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TRAFFICABILITY OF SNOW, GREENLAND STUDIES, 1955 AND 1957

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May 1960

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GREENLAND STUDIES, 1955 AND 1957

TECHNICAL MEMORANDUM NO. 3-414

Report 3

May 1960

U. S. Army Engineer Waterways Experiment Station

CORPS OF ENGINEERS

Vicksburg, Mississippi

ARMY-MRC VICKSBURG, MISS

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PREFACE

As part of the over-all Corps of Engineers Greenland research program, the U. S. Army Engineer Waterways Experiment Station was assigned, by the Office, Chief of Engineers, the responsibility for correlating the trafficability of Greenland snow with the performance of existing vehicles. The phase of the study reported herein was conducted during the summers of 1955 and 1957. The 1955 work was authorized by the Office, Chief of Engineers, in January 1955, and the 1957 tests were authorized in March 1957.

This is the third report in the *Trafficability of Snow* series. Report 1 of the series, prepared under contract by Stevens Institute of Technology, Hoboken, N. J., is a review of available literature through 1954 on the subject of snow trafficability as related to the design of vehicles for travel on snow, and the prediction of the performance of vehicles in snow. Report 2 is a summary of the results of vehicle tests conducted by the Waterways Experiment Station in Greenland during the summer of 1954. This report (No. 3) is a summary of the results of vehicle tests conducted by the Waterways Experiment Station in Greenland during the summers of 1955 and 1957.

The work reported herein was performed under the Corps of Engineers subproject 8-70-05-400, "Trafficability of Soils as Related to Mobility of Military Vehicles," by personnel of the Army Mobility Research Center, Waterways Experiment Station, under the supervision of Mr. W. J. Turnbull, Chief, Soils Division; Mr. C. R. Foster, Assistant Chief, Soils Division; and Mr. S. J. Knight, Chief, Army Mobility Research Center. The field program was conducted and this report was prepared by Mr. A. A. Rula, Chief, Trafficability Section, Army Mobility Research Center. Mr. C. A. Blackmon, engineering aide, provided major assistance in preparing tables and plates, and performing many of the computations reported herein.

Acknowledgment is made to the U. S. Army Engineer Arctic Task Force for furnishing test vehicles, vehicle operators, and quarters and rations for the test party during the period of field work; to the Transportation Corps Arctic Test Team for providing vehicles, quarters, and rations for the October 1955 test period; to the East Ocean Division for the loan of equipment for the 1957 season; and to the U. S. Army Snow Ice and Permafrost Research Establishment for the loan of snow testing equipment and for providing the services of Mr. R. T. Van Slambrook, who was of major assistance during the 1955 program in classifying the snow and measuring snow properties pertinent to this study. Acknowledgment is also made to Dr. R. W. Gerdel of the Snow Ice and Permafrost Research Establishment, for his assistance in preparing an operational plan of tests for the 1955 program.

Directors of the Waterways Experiment Station during the course of this study and preparation of this report were Col. A. P. Rollins, Jr., CE, and Col. Edmund H. Lang, CE. Technical Director was Mr. J. B. Tiffany.

TRAFFICABILITY OF SNOW, GREENLAND STUDIES, 1955 AND 1957

SUMMARY

Self-propelled, towing, and towed tests were conducted with several wheeled and tracked military vehicles on dry and moist, fine-grained and wet, coarse-grained snow in Greenland during the summers of 1955 and 1957. The 1955 tests were conducted at various sites on or adjacent to a marked trail, approximately 220 miles long, leading from the edge of the ice cap at TUTO to Camp Fist Clench out on the ice cap; all 1957 tests were run at mile 30 on this route. The objectives of the study were to (a) correlate vehicle performance with snow-property measurements, (b) select an instrument that can be used to measure snow trafficability and at the same time meet military specifications, and (c) distinguish snow conditions that permit a vehicle to travel from those that do not. Vehicle performance was correlated with ten methods of measuring snow strength and two physical snow properties, with cone index providing the best correlation. All instruments used in obtaining the desired snow-property data were adequate from the serviceability standpoint, but some were more efficient than others. The snow conditions prevailing during the test periods did not produce sufficient immobilizations to establish trafficability limits.

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CONTENTS (Continued)

PART I. INTRODUCTION

I. BACKGROUND INFORMATION

Purpose of comprehensive investigation.

1. The tests reported herein are part of a comprehensive study being conducted to determine the trafficability of Greenland Ice-Cap snow for existing military and special-purpose vehicles. The data required in such a determination consist principally of information concerning (a) the firmness of the snow, (b) topographic features, and (c) vehicle characteristics. By correlating the first two sets of data with the last, the types of vehicles that can move across the ice cap, and the manner in which they should travel can be established. Topographic features are usually shown in maps, but data concerning the supporting capacity of various types of snow and the ability of vehicles to travel in snow can only be obtained through field tests. Accordingly, this investigation comprised vehicle performance tests on the ice cap, and included a swing of 220 miles on the ice cap from the edge at Thule Take-off (TUTO)* to Camp Fist Clench.

General features of the ice cap from TUTO to Camp Fist Clench.

2. On the basis of the data collected in 1955, the following general statements can be made concerning the trafficability of the ice cap from the edge at TUTO for a distance of 220 miles along a marked route.

Along the first 60 miles of the route, both melt and transition zones are encountered in the snow, and the rolling hill country contains significant slopes and unidentifiable snow-bridged crevasses which impede vehicle movement. During the summer season, melting of the previous year's accumulation of snow varies from rapid and complete melting near the edge of the ice cap (melt zone) to only slow and partial melting at higher elevations (transition zone). In the melt and transition zones the snow strength is usually sufficient to permit tracked vehicles with low ground-contact pressures to travel with ease, but only occasional limited going is possible with conventional wheeled vehicles even at low tire pressures. Repetitive traffic (usually greater than 25 passes) in these zones is conducive to ridge and swale development along the rut surface, which usually necessitates a decrease in speed. There are periods during the melt season when the snowpack on the ramp and in low-lying areas in the transition zone becomes saturated with water, thus occasionally restricting traffic to tracked vehicles that exert the lowest ground pressures. Local variations in melting of the ramp face and dissection by glacier streams create a rough, hummocky surface which makes movement on the ice ramp slow and difficult for all vehicles. From the top of the ramp to an elevation of approximately 4000 ft msl the melt period may produce, in level areas, local deposits of large snow crystals that when wet act like "greased marbles," and reduce traction.

Once the areas of little or no snow melting are reached, the over-all effect of the factors that impede vehicular movement decreases. The strength of the snow is adequate to permit easy going for low ground-pressure tracked vehicles, but only limited going on the best snow conditions is possible for conventional wheeled vehicles. The slopes encountered when moving toward the center of the

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* An ice ramp at the edge of the ice cap, located approximately 14 miles southeast of Thule, Greenland. The slope of the ramp varies from 3 per cent near the toe to about 10 per cent midway up the ramp.

ice cap are insignificant. Repetitive traffic will cause the formation of ridges and swales along rut surfaces, but broad areas of smooth surface snow permit the dispersion of vehicles over as many trails as desirable.

Occasionally, meteorological elements combine to restrict visibility to such low limits that vehicle movement is impossible. The condition in which visibility is restricted is called a "white-out"; its intensity is dependent upon the prevailing weather elements. The mildest form of a "whiteout" is an overcast sky that makes the horizon indiscernible. When blowing snow or fog accompanies the overcast sky, visibility may be restricted to 100 ft or even less.

II. THE PROBLEM

3. The evaluation of unimproved terrain to determine its trafficability, or its ability to support the passage of vehicles, requires consideration of local environmental factors as well as vehicle characteristics. In this broad sense, the problems encountered in trafficability studies are numerous and complex. For example, the cross-country movement of vehicles is dependent upon effects of the strength of the supporting material (soil or snow), slope, surface roughness, obstacles, and vehicle characteristics, and also on such secondary factors as visibility, driver skill, and the mechanical condition of the vehicles. Information on some of these factors, such as slope or obstacles, is usually available in the form of maps for evaluation purposes. The strength of the supporting material, however, is constantly being influenced by weather, which makes it a difficult factor to evaluate.

III. PURPOSE AND SCOPE OF 1955 AND 1957 TESTS

4. The specific objectives of these tests were (a) to correlate the performance of self-propelled and towed vehicles with snow-property measurements, and (b) to select an instrument that can be used to measure snow trafficability and that will meet such military specifications as simplicity, light weight, portability, and speed of readings.

The 1955 and 1957 programs included three types of tests on virgin and compacted snow: (a) self-propelled tests in which a vehicle was permitted to travel over the same straight path until it became immobilized or until 10 passes were completed; (b) towing tests in which the maximum drawbar pull that a vehicle could develop on the first pass was determined; and (c) towed tests in which the force required to pull vehicles on the first pass was measured. Vehicle performance was correlated with snow strength as determined by ten different methods and two physical snow properties.

IV. DEFINITIONS

5. Certain words and terms used in this report are defined below. The terms applicable to snow are defined first, followed by trafficability terms, strength terms, vehicle terms, statistical terms, and instrument, equipment, and test methods terms. The "strength terms" are those used to express the strength of snow.

Snow Terms

Snow. Solid precipitation formed in the atmosphere by *sublimation* of water vapour onto minute solid nuclei.*

* University of Minnesota Interim Report to Snow Ice and Permafrost Research Establishment, SIPRE Report No. 1, Minneapolis (January 1950).

Snow crystal. A single crystal, either regular or irregular, of snow.*

Coarse-grained snow. Snow crystals having a mean diameter larger than 2 mm.

Fine-grained snow. Snow crystals having a mean diameter 2 mm and less.

Column. A snow crystal in the form of a short hexagonal prism with either plane, pyramidal, or truncated ends (length-diameter ratio less than 5).*

Needle. A slender needlelike snow crystal usually having a structure consisting of needlelike components lying parallel and closely knit together (length-diameter ratio greater than 5).*

Hoar. Crystals formed by sublimation of water vapour onto any fixed object.*

Depth hoar. Hoar crystals, usually of cup shape, which have grown in cavities within the snow cover.*

Melt zone. An area in which complete melting of the snowpack takes place during the summer season.

Transition zone. An area in which only a portion of the yearly accumulation of snow is lost by melting.

Dry zone. An area in which little or no melting of the snow occurs during the summer season.

Density. Mass contained in a unit volume; in this report density is numerically equal to the unit weight of snow expressed in grams per cubic centimeter.

Trafficability Terms

Trafficability. The capacity of snow or soil to sustain traffic of military vehicles.

Bearing capacity. The ability of snow or soil to support a vehicle without excessive sinkage.

Traction capacity. The ability of snow or soil to provide sufficient resistance to the tread or track of a vehicle to furnish the necessary forward thrust.

Critical layer. The layer of snow or soil whose strength is considered a significant measure of trafficability.

Slipperiness. The condition that results in a decrease in the traction capacity caused by lubrication of a firm icy surface by a film of water.

Strength Terms

Cone index. An index of the shearing resistance of snow as measured with the cone penetrometer (described on pages 7 and 8). The value is considered a dimensionless number representing the resistance of a medium to penetration of a 30-degree cone of 0.5-sq-in. base area. The number, although considered dimensionless, is actually pounds of force on the handle divided by area of the cone base in square inches.

Remolding index. A factor that expresses the change in strength that may occur under traffic. The instruments and test procedures for determining the remolding index for snow are described on page 8.

Rating cone index. The product of cone index and remolding index.

Taper penetration index. An index of the shearing resistance of snow obtained with the taper penetrometer (described on pages 8 and 9). The value is the depth of penetration (expressed in inches) obtained with the application of a constant load.

Vane shear. A measure of snow shear strength obtained by rotating the shear vane (see page 9). Vane shear strength was measured at maximum torque (initial shear strength), and at the torque required to maintain rotation (residual shear strength).

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* Ibid.

At maximum torque the material sheared abruptly, and shear strength was computed according to the following formula wherein the shear stress on the two ends of the cylinder is assumed to vary directly with its distance from the axis of rotation, an assumption made frequently for similar tests in brittle material.

$$\tau_i = \frac{T}{\pi R^2 (R + 2H)}$$

where

τ_i = initial shear strength in pounds per square inch
T = total torsional moment in inch-pounds, or $T = T_e + T_c$ (see below)
H = height of shear vane in inches
R = radius (or one-half width of shear vane) in inches

The preceding equation is obtained by substituting the right-hand expressions of the following equations in the formula $T = T_e + T_c$ and solving for τ_i.

$$T_e = 2 \times \frac{\pi R^3 \tau_i}{2} = \pi R^3 \tau_i$$

$$T_c = 2\pi R^2 H \tau_i$$

where

T_e = torsional moment in inch-pounds for the ends of the cylinder
T_c = torsional moment in inch-pounds for the cylinder

Residual shear strength was computed according to the following formula in which it is assumed that shear stresses are uniform over the ends of the cylinder, which is frequently assumed in vane shear tests of plastic materials.

$$\text{Residual shear strength, } \tau_r = \frac{3T}{2\pi R^2 (2R + 3H)}$$

This equation is obtained by setting the following expressions equal to T and solving for τ_r.

$$T_e = 2 \times \frac{2\pi R^3 \tau_r}{3} = \frac{4\pi R^3 \tau_r}{3}$$

$$T_c = 2\pi R^2 H \tau_r$$

Torque tube shear. A measure of the shear strength of snow made by rotating a torque tube (described on page 9) under different normal loads in snow. "Moved" and "not moved" readings were made. For the "moved" readings, the torque tube was placed on virgin snow for each load reading. The "not moved" readings consisted of all readings taken in one spot. Shear occurs on the bottom of the tube only. A plot of a set of data results in apparent values of the cohesion and the angle of internal friction. The shear strengths at the peak torque and the torque required to maintain rotation were computed. Assumptions made in computing vane shear strength at the ends of the vane were also used in the torque tube computations. The formulas used are as follows:

$$\tau_i = \frac{2T}{\pi R^3} \text{ (initial torque)}$$

$$\tau_r = \frac{3T}{2\pi R^3} \text{ (residual torque)}$$

Variable-load vane shear. A measure of the shear strength of snow made by rotating a shear vane (described on page 10) under different normal loads in snow. The test method and subsequent use of the resulting values are the same as those used in the torque tube shear computations.

Unconfined compression. A measure of the shear strength of snow obtained by applying a load to a small cylindrical sample positioned in a compression device. Shear strength was computed from the formula

$$\tau = \frac{L(1 - 2\mu e)}{2} \times 14.2$$

where

τ = shear strength in pounds per square inch
L = load in kilograms per square centimeter (read directly from machine)
μ = Poisson's ratio
e = strain in per cent
14.2 = conversion factor from kilograms per square centimeter to pounds per square inch

Shearing of dry, hard snow usually occurred abruptly under small loads and strains, and it was assumed that the volume was constant, the strain and internal friction small, and hence that the cross-sectional area of the sample increased in accordance with a Poisson's ratio (μ) of 0.5. Substituting $\mu = 0.5$ in the preceding equation, the equation used for dry snow becomes

$$\tau_d = \frac{L(1 - e)}{2} \times 14.2$$

where

subscript d = dry snow

Wet snow samples and soft, dry snow samples usually shortened considerably, with no apparent change in cross-sectional area. For these snows

$$\tau_w = \frac{L}{2} \times 14.2$$

where

subscript w = wet snow

No attempt was made to test new, soft snow because such snow usually collapsed before a test specimen could be prepared.

Drop-cone hardness index. A measure of the hardness of the snow obtained with a drop-cone penetrometer (described on pages 10 and 11). The hardness index (measured in grams per cubic centimeter) is determined from a ratio of the forces exerted on the snow to the volume of the dent produced

by dropping of the cone. The hardness index is determined from the following equation.*

$$H = \frac{L\,(D + P)}{0.35\,P^4}$$

where

H = hardness index in grams per cubic centimeter
L = total load of cone in grams
D = height of drop in centimeters
P = penetration in centimeters

In this equation, $\frac{L\,(D + P)}{P}$ represents the force exerted on the snow by the cone, and $0.35\,P^3$ is equal to the dent volume produced by a 60-degree cone.

Canadian hardness. A measure of the shearing resistance of the snow obtained with the Canadian hardness gage (see page 11). The hardness value is the resistance to penetration, expressed in grams per square centimeter, computed from the observed spring tension and the area of the disk.

Ramm hardness number. An index of the shearing resistance (measured in kilograms) of snow obtained with the Rammsonde penetrometer (see page 11). The Ramm hardness number is determined from the following equation† in which the penetrometer assembly is considered completely elastic, and the total amount of energy developed in the fall of the penetrometer assembly is assumed to be transmitted to the cone as it penetrates the snow.

$$R\,\Delta x = P\,h\,n + (Q\,q + P)\,\Delta x$$

Solving the equation above for R, the equation becomes

$$R = (q\,Q + P) + \frac{P\,h\,n}{\Delta x}$$

where

R = hardness number
q = number of tube lengths
Q = weight of one tube in kilograms
P = weight of hammer in kilograms
h = height of fall in centimeters
n = number of blows of hammer between readings of x
x = depth of point of penetration below snow surface in centimeters; readings of scale (on tube) at snow surface
Δx = penetration in centimeters resulting from n blows. This is the difference between two successive values of x

Vehicle Terms

Pass. One trip of the vehicle over the test course.

Immobilization. For self-propelled vehicles, failure to complete a given number of passes (10) across a test course. For trailers or sleds, sinkage to the extent that the axle or undercarriage drags.

* Provided in letter from Dr. R. W. Gerdel, SIPRE, dated 21 September 1955.
† From SIPRE Form No. BR3-F4.

Towing force. The force required to move a tow load at a constant rate of speed.

Drawbar pull. The pull that is exerted at the drawbar of a vehicle.

Tractive coefficient. A ratio obtained by dividing the maximum drawbar pull by the towing vehicle test weight.

Vehicle cone index. The minimum rating cone index that will permit the vehicle to complete 40 to 50 passes.

Vehicle compaction index. An index of the strength change that occurs in snow as a result of compaction by vehicular traffic; numerically, it is the ratio obtained by dividing the average after-traffic (1 or 10 passes) cone index by the average before-traffic cone index.

Mobility index. A number, resulting from a consideration of certain vehicle characteristics, used as an index to vehicle performance. Refer to Waterways Experiment Station TM 3-240, *Trafficability of Soils*, 9th Supplement, for additional information.

Statistical Terms

Deviation. The difference between a plotted point and its corresponding curve measured along a rectangular coordinate.

Per cent error. The percentage ratio of the deviation of a given point to its corresponding value from the curve measured along the same coordinate.

*Method of least squares.** A mathematical method of determining the line of best fit to a series of data. The line is placed such that the sum of the squares of the deviation will be minimum.

*Linear regression.** A regression line determined by the method of least squares through a series of data.

Correlation coefficient. A statistical measure of the relation between two variables. It is determined by the formula

$$r = \frac{Sxy}{\sqrt{(Sx^2)(Sy^2)}}$$

The value of r can vary between -1 and +1. A value of ±1 indicates perfect correlation and a 0 value indicates no correlation. A plus value of r indicates that as one variable increases the other also increases, and a negative value of r indicates that as one variable increases the other variable decreases.

The statistical significance of the correlation coefficient is based on the degrees of freedom as well as the numerical value. A correlation coefficient significant at the 1 per cent level indicates that for the number of samples made, there are 99 chances out of 100 that the relation determined is the real relation of the two variables. For a correlation coefficient significant at the 5 per cent level, the relation determined is the real relation in 95 chances out of 100.

*Standard error of estimate.** A measure of the variation of observed values from computed values of a dependent variable. It yields an estimate of the range above and below the line of regression within which two-thirds of the points may be expected to fall, if the scatter is normal. In this report the standard error of estimate is symbolized by "Sy.x."

Instrument and Equipment Terms and Test Methods

Cone penetrometer. The cone penetrometer is a field instrument consisting of a 30-degree cone with a 0.5-sq-in. base area mounted on one end of a 36-in. shaft, and a proving ring with dial

* George W. Snedecor, *Statistical Methods*, 4th ed. (Ames, Iowa, Iowa State College Press, 1953).

gage and handle mounted on the other (see Fig. 1). The force required to move the cone slowly through a material is indicated on the dial inside the proving ring. A ring that deflects 0.1 in. under a capacity load of 50 lb and gives a cone index reading of 100 was used in snow.

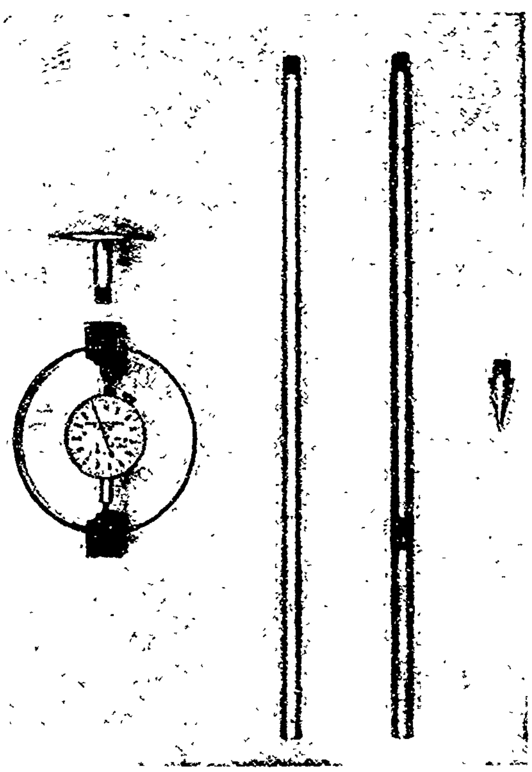


Figure 1. Cone penetrometer.

Remolding and compaction equipment. This equipment consists of (a) a 5000-cc, thin-walled cylinder, 6 in. in diameter and 10.80 in. long, which can be mounted on a 0.25-in.-thick detachable base plate; (b) a 3-lb drop hammer which travels 12 in. on an 18-in. section of a cone penetrometer staff fitted with a handle on one end and a circular foot 5.5 in. in diameter on the other end; and (c) a cone penetrometer equipped with an 18-in. shaft (see Fig. 2).

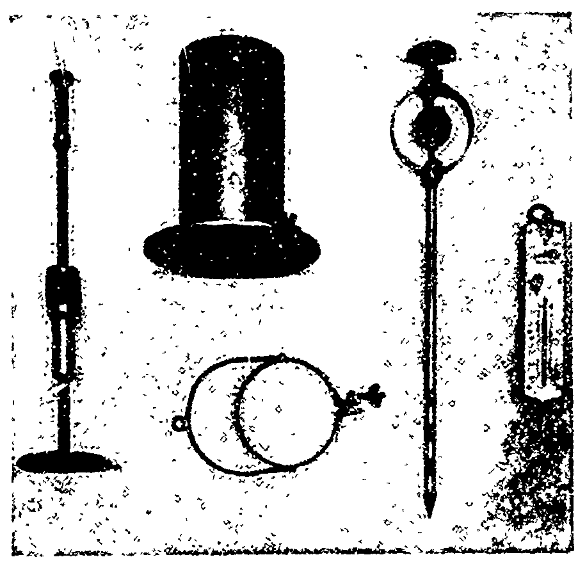


Figure 2. Remolding equipment.

In the test a sample is obtained by carefully forcing the top end of the 6-in.-diameter cylinder into the snow vertically until the bottom of the cylinder is flush with the snow surface (if the surface of the snow in the cylinder is lower than the surrounding snow surface, the snow is resampled until a relatively undisturbed snow sample is obtained); then the cylinder is carefully removed from the snowpack with a shovel, the bottom of the specimen is trimmed flush with the end of the cylinder, and the metal base is fastened to the bottom of the cylinder. An adapter to which a handle is fitted is then placed around the cylinder, and the sample is weighed for density determination. The adapter and base are removed from the cylinder, and the top end of the cylinder is placed on the base. Cone index readings are made at the surface of the sample and at 1-in. vertical intervals to a depth of 8 in. Then blows of the hammer are applied, and cone indexes are remeasured at 1-in. increments to a maximum depth dependent upon the amount of compaction that has occurred. The average cone index "after blows" is divided by the average cone index "before blows" to obtain the remolding index.

In obtaining the compaction characteristics of snow, these same sampling procedures are followed except that cone index measurements are made after a series of blows have been applied to the same sample.

Taper penetrometer. This penetrometer, designed by Dr. A. A. Warlam, consultant, is a field instrument weighing about 6.5 lb and consisting of a hollow 3-degree pyramidal staff, graduated in 1-in. increments to 30 in., with a spring-type loading device mounted on top of the staff (see Fig. 3). The spring which connects the two arms can be adjusted so that when the arms are depressed to reach a nearly horizontal position a constant force is applied at the point of the staff. The depth to which the

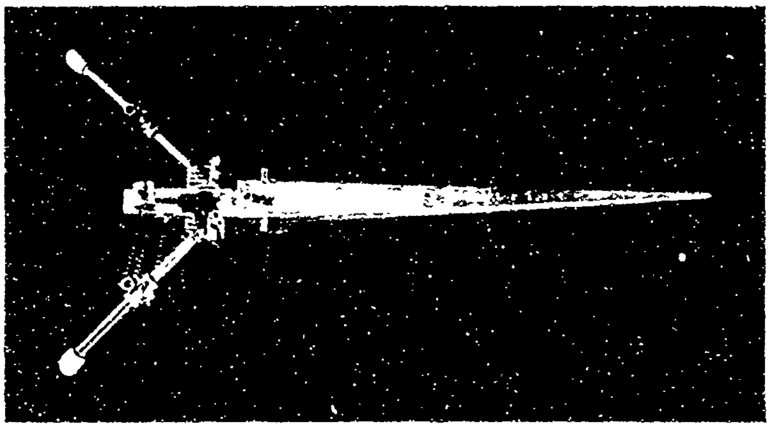


Figure 3. Taper penetrometer.

taper penetrates the snow is a measure of snow firmness. The remolding effect is determined by measuring the increase in penetration that results from twisting the instrument while the maximum load is maintained. Readings involve measuring the depth of penetration of the taper at "no load" (instrument weight only), at the maximum load, and after ten 90-degree twists of the taper in a clockwise, then counterclockwise, direction with the maximum load maintained.

Shear vane. This instrument is used in the field to determine the shear strength of snow layers. The shear vane (Fig. 4) consists of a 3/8-in.-diameter, 36-in.-long staff on one end of which four rectangular blades, each 4 in. long and 1 in. wide, are mounted at right angles to each other, and a torque wrench. The vane is pushed into the snow to the desired depth, and the amount of torque required at the top of the rod to rotate the vane in the snow is determined by means of the torque wrench. Readings are made at the maximum torque, and at the torque required to maintain rotation after initial shear (residual shear). The initial shear represents the strength of the undisturbed snow, and the residual shear represents the remolded strength.

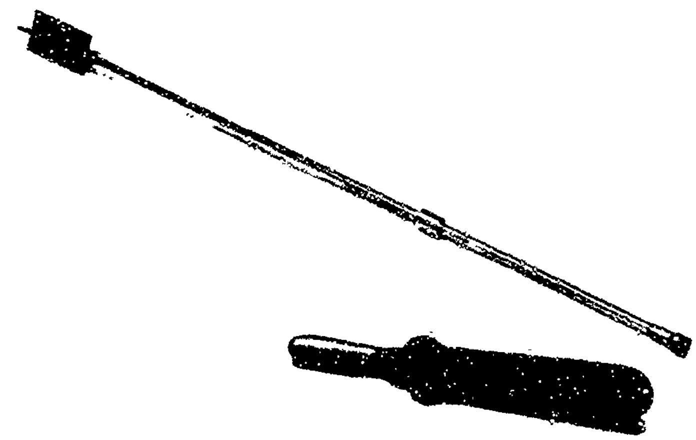


Figure 4. Shear vane apparatus.

Torque tube. This is a portable field instrument designed by the Snow Ice and Permafrost Research Establishment (SIPRE) to measure the cohesion and angle of internal friction of in-place snow (see Fig. 5). The equipment consists of a thin-walled tube with a set of vanes placed at right angles to each other inside one end of the tube, a cover, slotted for a torque wrench, locked into place on the other end, and a set of lead weights. The diameters of the tubes used were 2 1/4 in., and 5 in. The instrument is loaded at various unit pressures (usually 1-5 psi), placed on the snow, and torque readings are obtained at the maximum torque required to shear the snow and at that required to maintain rotation after shear has occurred. The normal loads are plotted against the computed shear strength to determine the cohesion and angle of internal friction of the snow. Because of the corkscrew action of the instruments resulting when the different loads were placed in the same hole, "moved position" readings were also made.

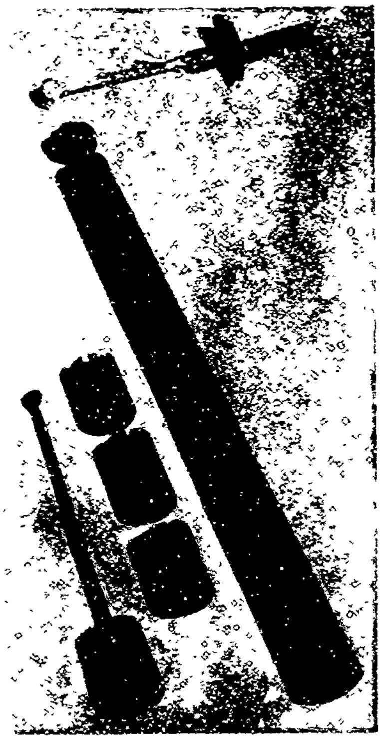


Figure 5. 2-1/4-in.-diameter torque tube equipment.

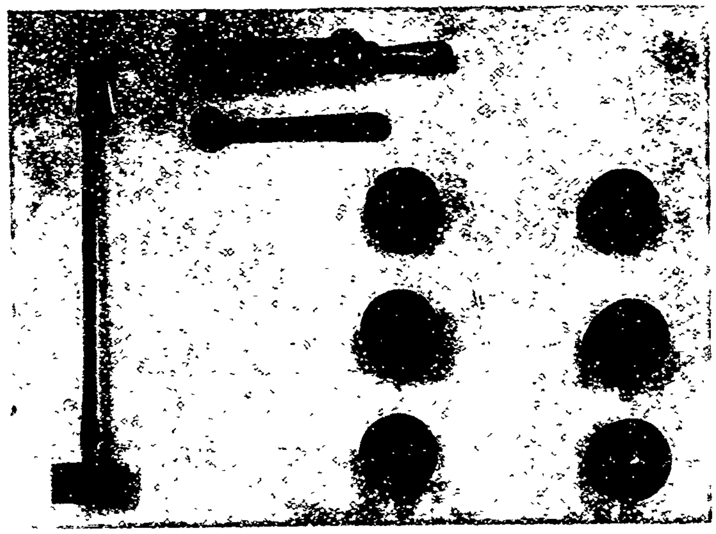


Figure 6. Variable-load shear vane.

Variable-load shear vane. The equipment consists of a 10-sq-in.-area, circular plate, 0.25 in. thick, with a set of thin vanes, 1.50 in. high, mounted at right angles to one side of the plate, and a 0.5-in.-diameter rod 18 in. long, with a torque wrench adapter, mounted to the other side. A range of loads from 0.25 to 5 psi is applied to the plate with lead weights, 10 sq in. on end, and slotted to fit on the shaft (see Fig. 6). The method of operation and the values obtained with this instrument are similar to those obtained in tests with the torque tube.

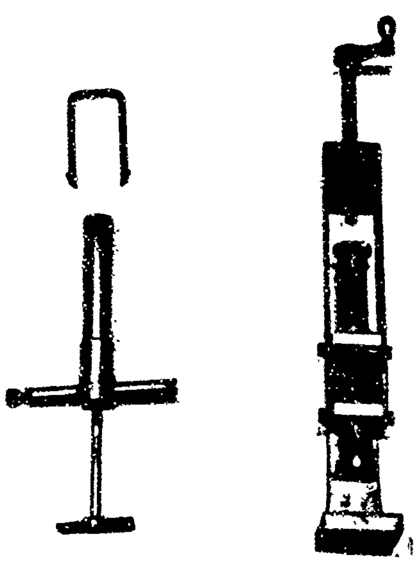


Figure 7. Unconfined compression apparatus.

*Unconfined compression apparatus.** This portable field apparatus (Fig. 7), designed by Dr. M. J. Hvorslev, consultant, Waterways Experiment Station, permits a quick and easy determination of unconfined compressive strength of small soil samples. The equipment consists of a constant-volume, piston-type sampler, and a base with a guide frame and a loading unit. The loading unit consists of a pair of telescoping tubes with helical compression springs. The movement of the inner tube with respect to the outer tube indicates the load, whereas the movement of the outer tube with respect to the guide frame indicates the deformation of the sample. A sample, 1 in. in diameter and 2 in. high, is used in the test. The load is applied by turning a screw which compresses the spring mounted in the inner tube.

Drop-cone penetrometer.† This instrument consists of a sheet-aluminum cone with a 60-degree vertex angle, weighing 0.5 kg, and having a central spindle, a graduated supporting rod 80 cm long mounted on a flat base, and a movable, horizontal arm equipped with a bubble level and a trip lever fitting a notch on the cone spindle (Fig. 8 shows drop-cone penetrometer in use). It is provided with a set of weights, two 0.5-kg, one 1.0-kg, and one 2.0-kg, which can be slipped over the cone spindle. In operation the movable arm is set at a preselected height on the support rod, the appropriate weight placed on

* M. Juul Hvorslev "Pocket-size piston samplers and compression test apparatus," *Proceedings, Second International Conference on Soil Mechanics and Foundation Engineering*, Rotterdam, Netherlands, vol VII (1948), pp. 76-79.

† U. S. Army SIPRE CE, op. cit.

Figure 8. Drop-cone penetrometer in use.

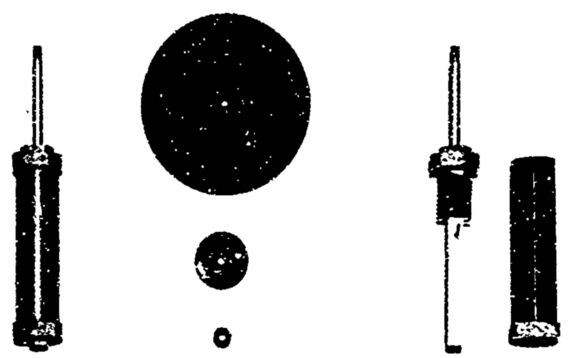


Figure 9. Canadian hardness gage.

the cone spindle, and the spindle located in the trip lever on the movable arm. The cone is dropped by releasing the trip lever, and the graduated support and movable arm are used as a gage to measure the depth of penetration of the cone into the snow.

*Canadian hardness gages.** These gages are small, cylindrical, push-type, spring-loaded balances (see Fig. 9) which can be operated with one hand. They are provided with a threaded plunger on which disks of several sizes can be mounted. High- and low-range gages with interchangeable disks are supplied. The low-range gage is recommended for measuring hardness up to 1000 g per cm^2 and the high-range gage is recommended for more than 1000 g per cm^2. In operation, the barrel of the gage is held in the hand and the disk pressed against the snow until a definite collapse of the snow surface is observed. The spring tension at collapse is read on the near end of the plunger which extends through the back of the cylindrical case.

Rammsonde penetrometer. This instrument is used in the field to determine the relative strength of snow layers to considerable depths. The equipment consists of several hollow tube sections, each weighing 1 kg, graduated in centimeters, 1 m long, and 20 mm in diameter (Fig. 10). At the end of one of the tubes is a 60-degree conical point which has a diameter of 40 mm and tapers back to the rod. A metal rod, 55 cm long and graduated in units of 10 cm, is mounted on top of the penetrometer and is used to guide the driving hammer (1, 2, or 3 kg in weight).

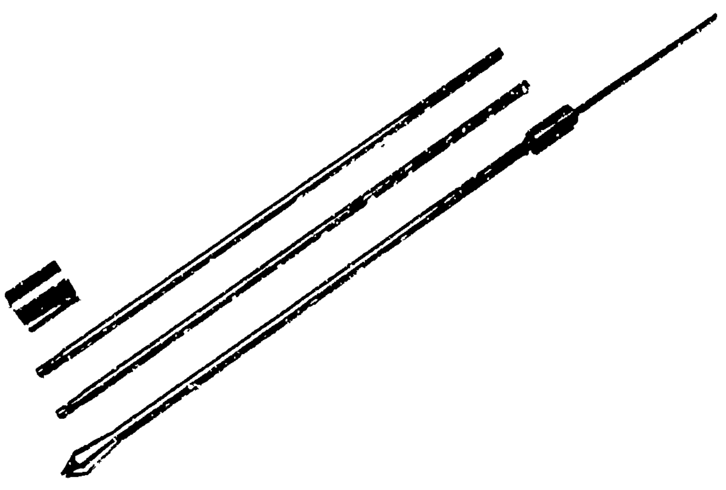


Figure 10. Rammsonde penetrometer.

* U. S. Army SIPRE, CE, op. cit.

PART II. TEST PROGRAM

V. FIELD OPERATIONS

6. The 1955 field program was conducted along the marked route, previously described, leading from the edge to a point approximately 220 miles toward the interior of the ice cap. The test team employed a self-sustaining, mobile swing which permitted them to test a wide range of snow conditions encountered during the summer period along the route traveled. Elevations along the route varied from 1560 ft msl at the toe of the ice ramp to about 7200 ft msl at the end of the 220-mile route. The tests made in October 1955 by the Transportation Corps Arctic Test Team were conducted in the vicinity of mile 31 from the edge of the ice cap. For the 1957 test program, a semipermanent camp was established at mile 30, at an elevation of approximately 2800 ft msl, and testing was restricted to that vicinity.

VI. TEST AREAS

Selection.

7. An effort was made during both programs to test a range of snow conditions that would be representative of those encountered during the summer season. In 1955 a variety of snow conditions was sought by traveling over an established ice-cap trail approximately 220 miles in length, whereas in 1957 a late spring and summer program was conducted at one location, with the changing weather producing a variety of snow conditions. Although both level and sloping areas were available along the first 60 miles of the 1955 test route, testing was restricted to known level, uncrevassed areas only because movement to and from slope areas usually required traversing heavily crevassed areas. At the beginning of the 1955 field program, a quick trip was made to mile 220 to determine the range of snow conditions that could be expected. En route vehicle tests were made at only five sites, but snow survey pits were dug at 20-mile intervals and snow properties ascertained. At mile 220 a preliminary analysis was made of the snow data obtained, and areas presenting the widest range in snow conditions not previously tested were selected for tests on the return trip.

Location.

8. The locations of the test sites are shown in Plate 1 where they are designated by letters A through J. On the 1955 trip into the ice cap, vehicle tests were conducted at miles 0, 7, 60, 122, and 220 (test sites A, B, F, H, and J, respectively) and on the return trip at miles 150, 70, 32, and 8 (test sites I, G, E, and C, respectively). As previously stated, a few of the 1955 tests were also run at mile 31 (test site D) at a later date. All 1957 tests were conducted at mile 30.

VII. SNOW CLASSIFICATION PROCEDURES

9. The snow classification test procedures contained in SIPRE's Instruction Manual No. 1, *Instructions for Making and Recording Snow Observations*, and SIPRE's snow card, *Simplified Field Classification of Natural Snow Types for Engineering Purposes*, were adopted for this study except that a very soft snow was included in the classification of snow hardness. The terms and procedures used in this study to classify snow as to grain nature, hardness, and wetness are defined in the following tabulations:

Code	Symbol	Grain Nature
Fa	+ + +	New snow (original crystal forms such as stars, plates, prisms, needles, and grouped granules are recognizable).
Db	□ □ □	Old snow, granular, fine-grained (mean diameter is less than approximately 2 mm; like table salt).
Dd	o o o	Old snow, granular, coarse-grained (mean diameter is larger than approximately 2 mm; like coarse sand).
De	∧∧∧	Depth hoar (cup-shaped crystals 3-10 mm in diameter, usually found near the bottom of snowpack).

Code	Symbol	Hardness (gloved hand)
Ka		Very soft (back of hand)
Kb		Soft (four fingers)*
Kc		Medium hard (one finger)*
Kd		Hard (pencil)*
Ke		Very hard (knife)*

* The object indicated, but not the preceding one, can be pushed into the snow without considerable effort.

Code	Symbol	Wetness (gloved hand)
Wa		Dry (snowball cannot be made)
Wc		Moist (does not obviously contain liquid water, but snowball can be made)
Wd		Wet (obviously contains liquid water)
We		Slushy (water can be pressed out)

VIII. SNOW CONDITIONS TESTED

1955.

10. The 1955 test program was conducted during the period 18 June to 11 August. Vehicle tests were conducted on wet and moist, coarse-grained snow, and dry and moist, fine-grained snow. Throughout the entire distance traveled from mile 0 to mile 220, a decrease in temperature together with an

increase in altitude resulted in a general tendency for the wetness of the snow to decrease, the crystal size to become smaller, and densities to become lower. In general, wet and, occasionally, moist coarse-grained snows were encountered from the edge of the TUTO Ramp to mile 48 (elevation 4000 ft msl), moist fine-grained snow and some moist coarse-grained snow were encountered from mile 48 to mile 70 (elevation 4500 ft msl), and dry snow was found along the remainder of the route. The tests run at mile 31 in October were in dry fine-grained snow. At each test site variations in crystal size, hardness, and density were noted. Ice lenses were encountered in varying degrees as far as mile 122; none were found beyond that point. Several snowfalls occurred during the course of the test program. Plate 2 shows snow profiles investigated at each 1955 test site, and the following tabulation lists data pertinent to the surface foot of virgin snow encountered at each site.

Mile	Test Dates	Crystal Size, mm	Density g/cm³	Temp °C	Wetness	Hardness	Remarks
0	18 June	2-8	0.44	−1	Wet	Soft	Glacier ice at 24 in.
7	24 June-3 July	2-8	0.44	0	Wet	Soft to medium hard	Numerous ice lenses
8	9 Aug.	2-8	0.46	0	Wet to moist	Soft to medium hard	Numerous ice lenses
31	4-6 Oct.	0.5-2.0	0.28	−13	Dry	Soft	3 in. of new snow on 5 October. Old, hard snow below 12 in.
31	17-20 Oct.	0.5-2.0	0.28	−15	Dry	Soft	Old, hard snow below 30 in.
32	5-7 Aug.	2-6	0.46	−1	Moist to wet	Soft to medium hard	Numerous ice lenses
60	5-6 July	1-2	0.39	−1	Moist	Soft	
70	31 July-1 Aug.	0.5-1.5	0.33	−9	Dry to moist	Soft to medium hard	Few ice lenses, 2-4 in. of new snow
122	10-11 July	0.5-1.0	0.33	−6	Dry	Medium hard to soft	Numerous ice lenses
150	25-27 July	0.25-1.0	0.28	−11	Dry	Soft	
220	14-22 July	0.25-1.0	0.23	−9	Dry	Very soft	4-6 in. of new snow

1957.

11. The 1957 test program was conducted during the period 3 May to 7 July. At the beginning of the test program, the snow was dry and fine-grained, and the previous year's accumulation ranged in depth from about 68 to 74 in. As the weather became warmer, crystal size and density increased, snow temperature increased, ice lenses formed within the snowpack, wetness changed successively from dry to moist to wet, and the depth of the previous year's accumulation of snow decreased to approximately 48 in. Near the end of the testing period some of the grain sizes exceeded 2.0 mm, but not in sufficient quantities to necessitate classification of the snow as coarse-grained. Plate 3 shows snow profiles obtained periodically during the 1957 test program, and the following tabulation lists data pertinent to the surface foot of virgin snow obtained at frequent intervals during the 1957 test period.

Test Dates	Crystal Size, mm	Density g/cm³	Temp °C	Wetness	Hardness	Remarks
3 May	0.25-0.5	0.34	-22	Dry	Soft to medium hard	
11 May	0.5-1.0	0.32	-10	Dry	Soft	
18 May	0.5-1.0	0.35	-6	Dry	Soft to hard	Surface layer slightly moist
27 May	0.5-1.0	0.36	-4	Dry	Medium hard to hard	
7 June	0.5-1.0	0.33	-3	Dry	Hard to medium hard	Surface layer slightly moist
12 June	0.5-1.0	0.40	-1	Dry	Medium hard	Ice lenses present, top 6 in. moist
18 June	1.0-3.0	0.51	0	Moist	Hard to medium hard	Ice lenses present
22 June	1.0-3.0	0.46	0	Wet	Soft to medium hard	
4 July	1.0-3.0	0.50	0	Wet	Soft to medium hard	Ice lenses present
7 July	1.0-4.0	0.50	0	Wet	Very soft to soft	Ice lenses present

IX. WEATHER DATA COLLECTED

12. Weather records, except for the October 1955 period of testing, are summarized in Tables 1 and 2. Weather data collected included air temperature, relative humidity, wind, sky cover, and type of precipitation. Because of difficulties encountered in measuring new deposits of blowing snow, new-snow depth measurements were not made except whenever a snow classification pit was excavated in conjunction with vehicle tests.

Air temperature and relative humidity were recorded continuously by means of a hygrothermograph, and the relative humidity was checked with a sling psychrometer during the morning observation period. In 1957 the hair element of the psychrometer failed to operate properly; therefore, relative humidity data are not shown in Table 2. Wind speed was measured by a portable anemometer in 1955 and by a fixed totalizing anemometer and velocity indicator in 1957. Visual estimates were made of sky cover during observation periods.

In 1955, daily weather data were observed and recorded at 4-hour intervals between 0800 and 2000 hours, and in 1957 these observations were made at 0700, 1200, and 1900 hours. The maximum, minimum, and average values shown in the tables for those data not continuously recorded were obtained from the several daily readings made. In 1957 the mean daily wind was obtained by averaging the total amount of wind passing the station in a 24-hour period, whereas maximum and minimum wind speeds were obtained from the few daily readings made. For this reason the values shown for maximum, minimum, and mean daily readings may not always be in normal agreement.

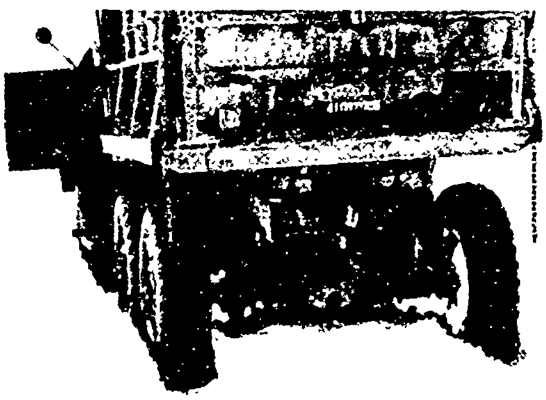
X. TEST VEHICLES

Classification by weight.

13. In this report, the vehicles with test weights of 10,000 lb or less are identified as lightweight vehicles. The lightweight vehicles include the weasel M29C, weight 5450 lb; the Sno-Cat 743, weight 8230 lb; and the otter M76, weight 9960 lb. Important physical characteristics of all vehicles tested are listed in Table 3. In the analysis of vehicle sinkage-performance data, an attempt was made to correlate snow-property measurements (using averages determined for different depths) with different vehicle weights and ground-contact pressures. The results indicated that the best correlations were obtained by considering the 0- to 6-in. depth for vehicles weighing 10,000 lb or less, and the 0- to 12-in. depth for vehicles weighing more than 10,000 lb.

Description.

14. *Wheeled vehicles.* In 1955 the following wheeled vehicles were tested: the 2-1/2-ton 6x6 truck M47, the Tournadozer, and the Terracruiser XM357. The data presented for the Terracruiser XM357 were obtained during the October test period when the Transportation Corps conducted engineering tests of this vehicle to determine its adaptability for ice-cap use. The wheeled vehicles tested are shown in Figure 11.



2-1/2-ton truck M47

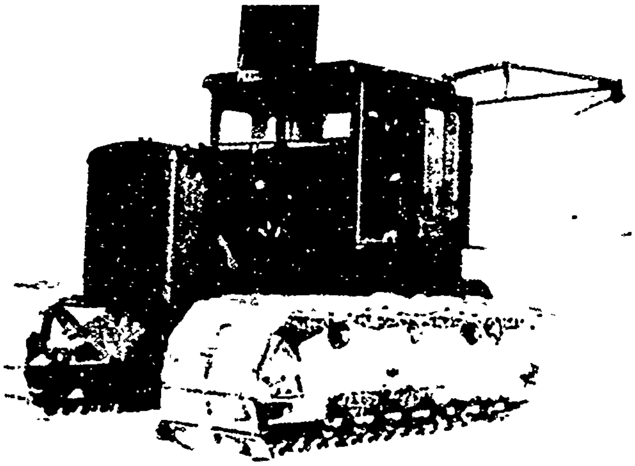
Terracruiser XM357

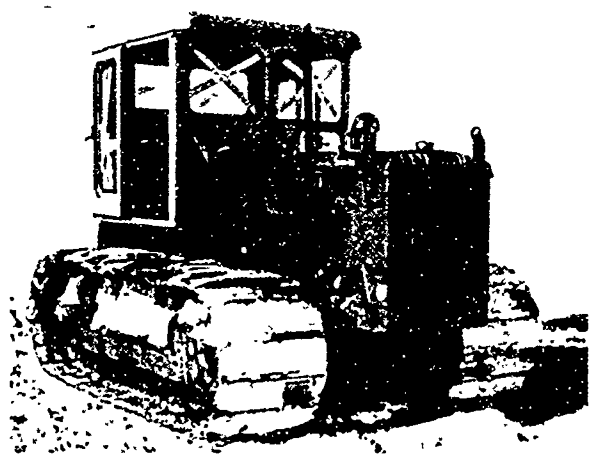
Tournadozer

Figure 11. Wheeled vehicles tested in 1955.

Tracked vehicles. Tracked vehicles commonly used for ice-cap operations were tested in both test programs. The 1955 tests involved the low ground-pressure LGP-D7 tractor, the standard D6 engineer tractor with 30-in. track pads, the otter M76, the Sno-Cat 743, and the weasel M29C. These vehicles are shown in Figures 12 and 13. All of these vehicles except the LGP-D7 tractor were tested in

LGP-D7 tractor





D6 tractor (30-in. track)

Sno-Cat 743

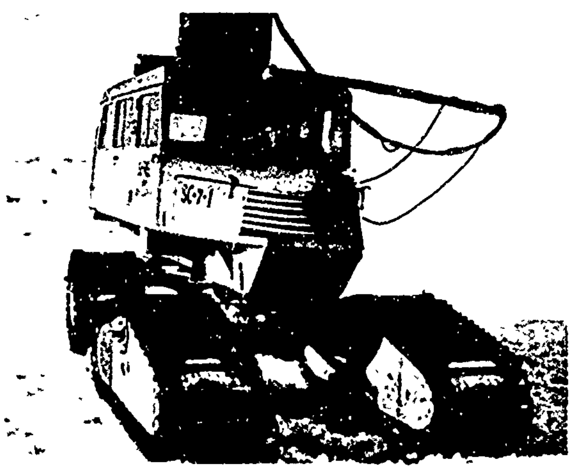
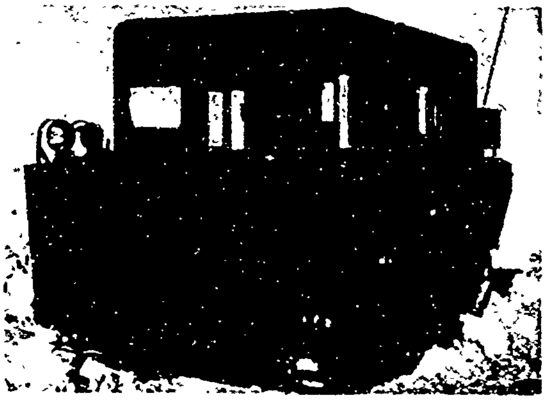
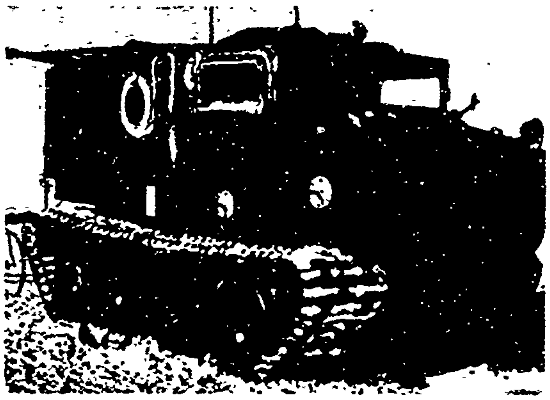


Figure 12. Three of the tracked vehicles (tractors and Sno-Cat) tested in 1955.



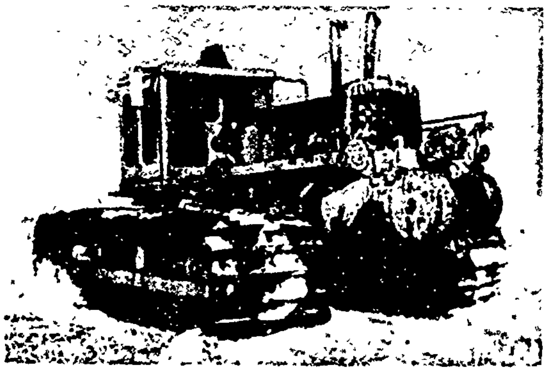
Weasel M29C



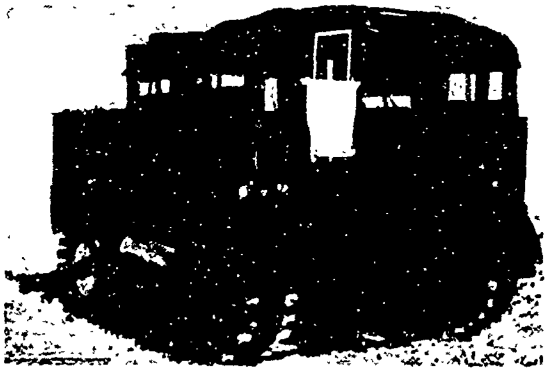
Otter M76

Figure 13. Other tracked vehicles tested in 1955.

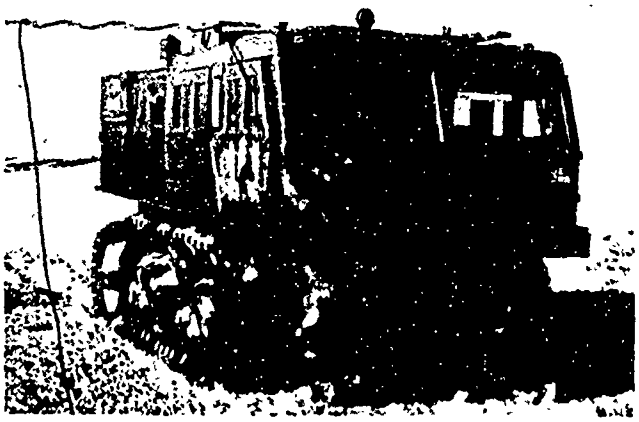
1957 also; in addition, an LGP-D8 tractor, hi-speed tractors M4 and M5A4, a medium tank M48, and an Athey wagon (tracked trailer) were also tested in 1957. The additional vehicles tested in 1957 are shown in Figures 14 and 15.



LGP-D8 tractor



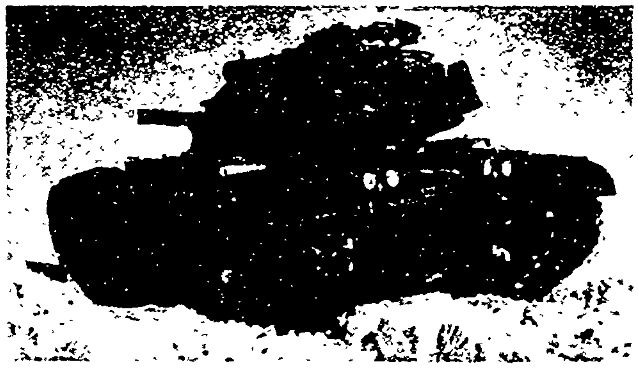
Hi-speed tractor M5A4



Hi-speed tractor M4

Figure 14. Additional tracked vehicles (tractors) tested in 1957.

Medium tank M48



Athey wagon BT898-4

Figure 15. Additional tracked vehicles (tank and Athey wagon) tested in 1957.

Sleds. During both test programs tests were conducted with the 10-ton Otaco cargo sled (Fig. 16). In 1955 tests were run with 5- and 10-ton payloads, and in 1957 these loads as well as a 15-ton load were used. Tests in 1955 were restricted to sleds with steel runners; in the 1957 tests, however, steel runners were compared with runners coated with two types of plastic material.

Figure 16. Ten-ton-capacity Otaco sled with 5-ton payload.

Difficulties encountered.

15. Vehicle difficulties encountered during the course of the test periods caused curtailment of certain test activities. In 1955 the 2-1/2-ton truck was transported by sled; however, the Tournadozer was too heavy to transport in this manner so it traveled under its own power, assisted by a prime mover, until snow conditions became so critical that it was returned to Camp TUTO. This occurred about mile 10. Also in 1955, an urgent need for an LGP tractor by other projects at Camp Fist Clench (mile 220) necessitated an exchange of the LGP-D7 tractor for another D6 tractor with a 30-in. track width. This resulted in the termination of tests with the LGP-D7 tractor, and since the D6 tractor has less

towing ability, it also caused the termination of some types of sled tests. At mile 32 on the return trip, the Sno-Cat 743 burned a wheel bearing, which prevented further drawbar-slip tests since this vehicle had been used as the instrument vehicle in such tests. In 1957, periodic mechanical failure of vehicles reduced the number of tests originally planned.

XI. TESTS

16. As stated earlier, self-propelled, towing, and towed tests were conducted. Single self-propelled tests were performed with all the tracked and wheeled vehicles listed in paragraph 14, pages 16, 17, and 18; however, the number of tests conducted with wheeled vehicles was rather limited because the mobility of the wheeled vehicles in most ice-cap snows was very poor. Towing tests were run with the LGP-D7 and LGP-D8 tractors, the D6 engineer tractor, hi-speed tractors M4 and M5A4, the medium tank M48, the weasel M29C, and the otter M76. Towing tests were not attempted with the Sno-Cat because it was used as the instrument vehicle and every precaution was taken to prevent its breakdown. The towed tests were performed with the Otaco 10-ton cargo sled, mounted with steel and plastic-coated steel runners, and the Athey wagon. Towed tests were also run to determine the force required to pull the self-propelled vehicles over the snow. The number and types of tests conducted during both test programs with each vehicle are summarized in the following paragraphs.

Vehicle tests conducted in 1955.

17. The locations, number, and types of tests conducted in 1955 are given in the following tabulations.

Tests Conducted at Each Location

Mile	Test Site	Self-Propelled	Towing	Towed	Total
0	A	2	0	0	2
7	B	14	4	0	18
8	C	3	0	0	3
31	D	7	0	0	7
32	E	5	3	2	10
60	F	7	0	0	7
70	G	5	5	2	12
122	H	4	1	2	7
150	I	5	3	2	10
220	J	6	7	6	19
	Total	58	23	14	95

Number and Type of Tests Performed with Each Vehicle

Vehicle	Self-Propelled	Towing	Towed	Total
	Wheeled			
Tournadozer	1	0	0	1
2-1/2-ton 6x6 truck M47	6	0	0	6
Terracruiser XM357	3	0	0	3
	Tracked			
Weasel M29C	12	12	5*	24
Sno-Cat model 743	5	0	0	5
Otter M76	8	4	0	12
D6 tractor (30-in. pads)	14	6	4*	20
LGP-D7 tractor	9	1	0	10
	Sleds			
Otaco, 10-ton capacity	0	0	14	14
Total	58	23	14	95

* Towed tests were conducted with the self-propelled vehicles, immediately after most towing tests, to measure the pull required to tow them in neutral gear over virgin snow. These tests have not been given separate test numbers, and they are not included in this tabulation, but their results are presented in the tables at the end of this report beside the towing test results.

Vehicle tests conducted in 1957.

18. The number and types of tests conducted in 1957 are given in the following tabulation.

Number and Type of Tests Performed with Each Vehicle

Vehicle	Self-Propelled	Towing	Towed	Total
	Tracked			
Weasel M29C	10	12	7*	22
Sno-Cat model 743	8	0	0	8
Otter M76	10	10	7*	20
D6 engineer tractor (30-in. pads)	12	6	3*	18
Hi-speed tractor M5A4	9	8	6*	17
Hi-speed tractor M4	12	10	6*	22
LGP-D8 tractor	5	5	4*	10
Medium tank M48	10	9	4*	19
	Tracked Trailer			
Athey wagon model BT898-4	0	0	4	4
	Sled			
Otaco, 10-ton capacity	0	0	119	119
Total	76	60	123	259

* Towed tests were conducted with the self-propelled vehicles, immediately after most towing tests, to measure the pull required to tow them in neutral gear over virgin snow. These tests have not been given separate test numbers, and they are not included in this tabulation, but their results are presented in the tables at the end of this report beside the towing test results.

Test procedures.

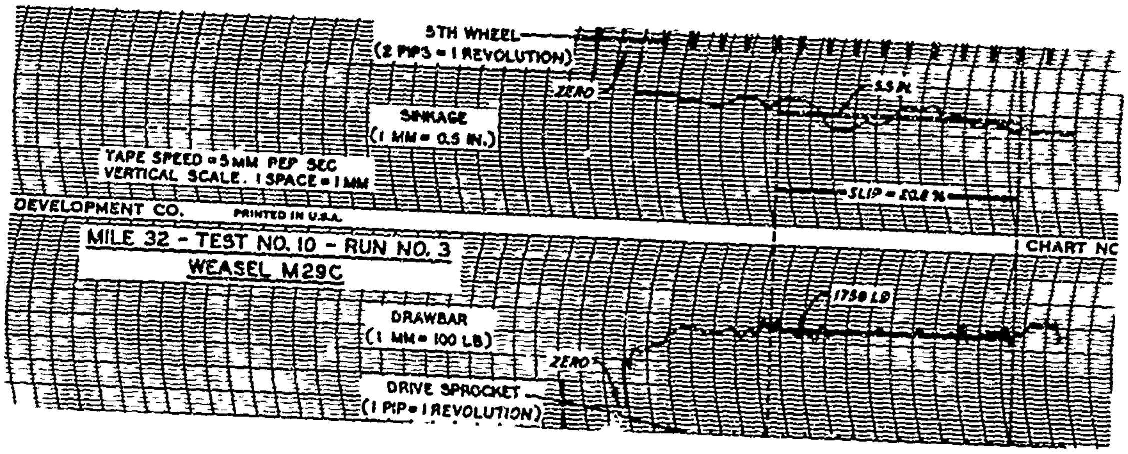
19. *Self-propelled tests.* A test lane 100 ft long and as wide as the test vehicle was staked out, the surface profile was recorded, and snow data were obtained. The test vehicle then entered the lane at Sta 0+00, proceeded slowly in its lowest gear to beyond Sta 1+00, and then stopped. The second pass was made by the vehicle backing up in the same tracks. Usually, forward and backward traffic were used; however, occasionally only forward traffic was imposed on the test lane, with the vehicle circling around outside the lane to enter again at Sta 0+00. After the first pass, rut-profile and snow-strength measurements were made. In all cases, the strength measurements were made immediately after traffic to minimize the effect of age-hardening. A pit, at least 2 ft deeper than the ruts formed by the test vehicle, was dug across one rut and extended into the undisturbed snow on each side of the rut. Thus it could be used for comparing the virgin and one-pass densities and hardness. Virgin snow classification data were also taken in the undisturbed portion of the pit. After the 10th pass was completed, data similar to that collected after one pass were taken, except that virgin snow classification data were not remeasured. For each test, notes were recorded describing the action of the vehicle during the test.

Whenever soft snow was tested the procedures were modified somewhat. The vehicle was first permitted to complete one pass, one-pass rut-profile and snow-property data were collected immediately, and then virgin snow data were collected adjacent to the ruts. This procedure minimized the disturbance of the test lane.

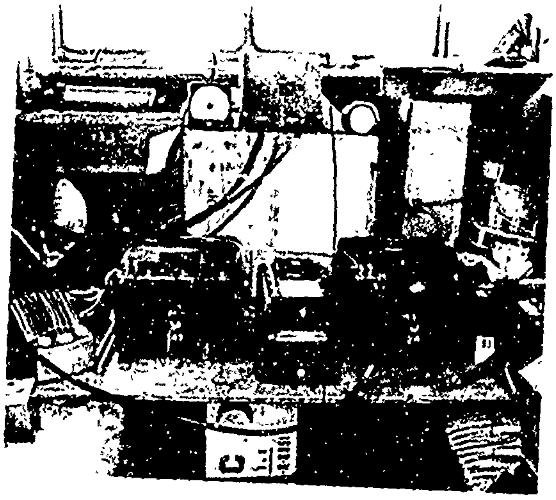
Towing tests. For the towing tests electrical and electronic instruments were mounted in the Sno-Cat 743 and connected to the towing and load vehicles to provide a continuous inked record of the drawbar pull, towing vehicle's sinkage, and a fraction of one revolution of the fifth wheel and drive sprocket. Drawbar pull and sinkage traces were obtained on two channels of a recorder which operated at a speed of 5 mm per sec, and the fifth wheel and drive sprocket data were recorded by event markers at the edge of the tape or on separate channels. The latter two measurements were

used to compute percentage of track slip. Track speed could also be computed from the number of revolutions completed by the fifth wheel per unit of time. A speaker system was devised so that the operators of the instrument vehicle, test vehicle, and load vehicle could communicate with each other. A milliammeter was tied into the dynamometer circuit and mounted on the load vehicle to assist the driver of the load vehicle in maintaining a desired load.

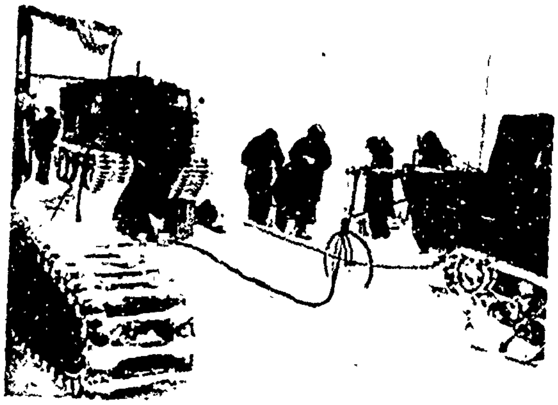
After the leads connecting the test vehicle to the instruments were in place, one end of a Baldwin load cell was fastened to the towing hitch of the test vehicle and the other end was fastened to a 30-ft-long towing cable which was attached to the load vehicle. The test lane, then, was the 30 ft between the two vehicles. By means of two Brush strain analyzers, values for sinkage and drawbar pull to be covered within a chart width of 40 mm were selected. Figure 17 shows this equipment in the instrument vehicle, the arrangement of vehicles during a test run, and a section of a tape trace obtained from a test run.



Section of tape record from towing test



Arrangement of instruments in Sno-Cat



Arrangement of vehicles for drawbar pull-slip test

Figure 17. Typical equipment used and data obtained in towing tests.

Drawbar pull-slip tests were run only on the first pass since this pass was the most critical. Attempts were made to run repetitive-pass tests, but difficulties were encountered in maintaining a steady load because of the ridges and swales that developed along the path of the load vehicle. The tests were performed at a constant sprocket speed to give a track speed of approximately 2 mph, and the test vehicle was always run in its lowest gear. On occasion several special tests were conducted that differed from the test procedure just described. These are discussed separately in this report.

Once the vehicles attained a steady state of motion, the first selected load was applied slowly by varying the speed or applying the brakes, or doing both simultaneously, on the load vehicle, or, if the load vehicle had a hydramatic drive, by putting it in reverse gear and varying the engine speed with the accelerator. After sufficient data were obtained, successive loads were applied until a high percentage of track slip was attained. The test was then terminated, and the drawbar pull-slip curve was drawn. A load slightly below the maximum was selected and the test was rerun in order to insure a test run of sufficient length to permit measuring after-traffic snow properties. After the rerun, zero-pass and one-pass data were collected in the 30-ft section between the test and load vehicles in the same manner as in the self-propelled tests. For each test, notes were recorded describing the action of the towing vehicle during the test.

Towed tests. In the majority of the towed tests, the 10-ton-capacity Otaco sled was towed by an LGP tractor. A dynamometer was fastened between the sled tongue and the drawbar of the tractor; or, in the tests in which the sled was towed over virgin snow, the dynamometer was hitched to one end of a 100-ft-long cable with the other end attached to a winch, and the 100 ft between the sled and winch constituted the test lane. The force required to start the sled moving and maintain steady motion at a speed of about 2 mph was measured. After a test was run, zero-pass and one-pass data were collected in a 50-ft section of the test lane in the same manner as in the self-propelled tests. For each test, notes were recorded describing the action of the towed vehicle during the test. In addition to the sled tests, towed tests were conducted with an Athey wagon trailer towed by an LGP tractor. In these trailer tests, a dynamometer was fastened between the trailer tongue and the drawbar of the tractor. The types of data collected and the procedures followed were the same as those for the sled tests. Also, towed tests were run with self-propelled vehicles in which they were pulled over virgin snow by a 100-ft-long cable to determine the force required to pull these vehicles.

Data collected.

20. In 1955 measurements were made with nine strength-indicating instruments to determine which type of measurement correlated best with vehicle performance. The measurements included cone index, remolding index, taper penetration, vane shear, torque-tube shear, unconfined compression, drop-cone hardness, Canadian hardness, and Ramm hardness. Subsequent analysis of the 1955 data revealed that cone index and shear strength determined with the shear vane gave the best correlations with vehicle performance; therefore, they were selected for snow-strength expressions for the 1957 program. However, compaction, rating cone index, Ramm hardness, and Canadian hardness measurements were also made in 1957 whenever tests were performed with vehicles that had been used in the 1955 test program. These vehicles included the weasel M29C, Sno-Cat 743, otter M76, and D6 engineer tractor. Also, strength measurements with a variable-load shear vane were made in 1957 in connection with the towing tests. During both test programs, rut profiles and snow-profile measurements, including density, temperature, grain nature, hardness, and wetness, were made. The frequency and depth of measurements made for each vehicle test are given in the following paragraphs.

Strength measurements. Strength measurements made were as follows:

Cone index. For each test, cone index data were usually taken in both tracks at 5-ft intervals, before traffic and after the first and last passes (10th). One set of readings consisted

of measurements made at 3-in. vertical increments to a depth of 18 in., then at 6-in. increments to a depth of 30 in. In firm snow the cone index readings were recorded to the nearest 5, and in soft snow to the nearest 1.

Remolding index. Undisturbed snow samples for the 0- to 10.8-in. depth were obtained in one track at Sta 0+25 and 0+75 to determine the remolding characteristics of the snow. The remolding index, temperature, and density of the whole sample were determined, and the decrease in height of the sample after compaction was measured.

Taper penetration. During the 1955 tests at mile 7 the taper penetrometer was broken beyond repair, thus limiting the data collected with this instrument to that obtained at miles 0 and 7. No-load, normal-load, and load-and-twist measurements were made before traffic and after the first and last passes. For each test measurements were made in one track at 10-ft intervals. The depth penetrated by the penetrometer was recorded to the nearest 1/4 in.

Vane shear. Shear-vane data were taken in both tracks at 10-ft intervals, before traffic and after the first and last passes. Initial and residual readings were made for the 0- to 6-in., 6- to 12-in., 12- to 18-in., and 18- to 24-in. layers.

Torque shear. For each days testing in 1955 at least one set of torque shear measurements was taken with the 2-1/4- and 5-in.-diameter tubes in virgin snow near the test areas. (However, at mile 60 the 5-in. torque tube was damaged beyond field repair, and subsequent tests were confined to the 2-1/4-in. tube.) Initial and residual torque readings were made with the torque tube. The 2-1/4-in.-diameter torque tube was loaded at unit pressures ranging from 1 to 5 psi, and the 5-in.-diameter torque tube was loaded at unit pressures ranging from 1 to 3 psi. Two sets of readings were made. For one set of readings, the tube was placed on undisturbed snow for each unit of loading, referred to in this report as "moved" position; in the other set of readings, the tube remained in the same spot for all unit loads, referred to in this report as "not moved" position.

Unconfined compression. Because of the difficulties encountered in obtaining test samples and testing the sample specimen, and the time consumed with each test, the data collected with this instrument were restricted to only a few measurements made in each of the different snow conditions tested in 1955. A vertical sample was obtained from each of the 0- to 6-in., 6- to 12-in., 12- to 18-in., and 18- to 24-in. layers. Data were taken in one track at Sta 0+50, before traffic and after the first and last passes.

Drop-cone hardness. In 1955 drop-cone data were taken in one track, before traffic and after the first and last passes. Three readings were made at both Sta 0+25 and 0+75. If the cone section did not remain in an upright position after being dropped, the test was repeated in accordance with instructions for using the drop-cone penetrometer.

Canadian hardness. Canadian hardness gage readings were made along the walls of a test pit excavated at Sta 0+50. Data were taken before traffic and after the first and last passes. Several measurements were made in each of the identifiable snow layers, and an average of the measurements obtained was recorded.

Ramm hardness. Ramm hardness measurements were made in one track to a depth of 60 cm at Sta 0+25 and 0+75. Measurements were made before traffic and after the first and last passes.

Compaction characteristics. Compaction characteristics of the snow were determined with the same equipment and using the same sampling procedures as those used in determining the remolding index. Samples were obtained in one track at Sta 0+25 and 0+75, and cone penetrometer readings

were made at 1-in. vertical increments throughout the depth of the sample and again after 5, 10, 20, 30, 50, and 80 blows of the drop hammer. The temperature and density of the sample, and the decrease in sample length after the prescribed number of blows were determined. Compaction vs cone index curves were drawn and used to determine the number of blows required in the cylinder to duplicate the change in cone index that occurred from compaction by one and ten passes, respectively, of a test vehicle.

Profiles. Rut profiles were measured with a level and rod at 5-ft intervals, after one and ten passes. Significant changes in elevation between the 5-ft intervals were also measured.

Snow classification. The equipment provided in the SIPRE snow kit was used to measure pertinent snow properties. Temperature, wetness, hardness, and grain nature of the virgin snow were measured in an undisturbed portion of a pit dug across one track at Sta 0+50 after one-pass traffic. This pit was dug to a depth of at least 24 in. below the ruts formed by the test vehicle. These snow properties were determined for each layer identified within the snow profile, except that temperature and density measurements were made at least in every 3-in. increment.

Density. Before traffic and after one and ten passes, density measurements were made to a depth 24 in. below the rut formed by a test vehicle. A pit was excavated across one rut at Sta 0+50 after one and ten passes, respectively, and 500-cc cylindrical samples, approximately 6 in. long, were taken along the center line of the rut. Before-traffic density measurements were made in an undisturbed portion of the pit dug after one-pass traffic. Density samples were obtained in each 3-in. layer by inserting the open end of the tube with a sharp edge into the wall of the pit in a horizontal position, and in each 6-in. layer by inserting the open end with a sharp edge parallel and adjacent to the wall of the pit.

Notes. Pertinent notes describing the action of the vehicle during the test were recorded. Such items as the station and pass number at which variations in rutting occurred, condition of the snow in the bottom of the ruts, pass number at which the vehicle undercarriage started to drag, and slippage were recorded for each test.

Tabulation of data. Whenever profile measurements (cone index, rating cone index, initial vane shear, residual vane shear, and density) were made at prescribed depths, numerical averages were computed using all the readings made within that layer considered to be critical for the vehicle and type of test under consideration. Weighted averages were used for the critical layer whenever readings were not made at predetermined depths. For those measurements that are considered surface measurements (torque tube, drop-cone hardness, and variable-load shear vane), numerical averages were determined.

XII. MISCELLANEOUS STUDIES

21. Miscellaneous studies pertinent to the scheduled vehicle tests included investigations of the effects of temperature, grain nature, density, and compaction on snow-strength measurements. In several cases the effects of age-hardening of the snow on the towing ability of several vehicles were determined. A correlation study of the various strength-measuring instruments used was made. The performance of the M48 tank on a trip to Fist Clench is also reported herein. The results of these studies are discussed in Parts III, IV, and V of this report.

PART III. FACTORS AFFECTING TRAFFICABILITY OF SNOW

22. The factors affecting snow trafficability are discussed in the following paragraphs. A discussion of trafficability factors is presented first, followed by a discussion of variations in snow

properties as they may affect the trafficability factors, after which a discussion of action of vehicles in snow is presented.

XIII. DISCUSSION OF FACTORS

Snow strength.

23. The trafficability of a snow is considered adequate if the snow has sufficient bearing capacity to support a vehicle without undue sinkage and adequate traction capacity to enable the vehicle to develop the necessary forward thrust to overcome its rolling resistance. Once the rolling resistance equals or exceeds the traction capacity, the vehicle becomes immobilized.

Slipperiness.

24. Under special conditions the movement of vehicles may be affected by slipperiness. Slipperiness occurs whenever sufficient traction cannot be developed between the wheels or tracks of a vehicle and a firm supporting material to provide a forward thrust. In Greenland, this condition is usually restricted to the edge of the ice cap where water or a shallow layer of snow occurs on firm ice. Immobilizations due to slipperiness are usually limited to wheeled vehicles both with and without chains or tracked vehicles with rubber grousers.

Remolding.

25. Strength changes resulting from the compaction of the snow by vehicular traffic are very important from the trafficability standpoint since the strength thus produced in the snow affects its trafficability. A single pass of a vehicle may transform a very soft snow into a fairly firm snow, which process makes each successive pass of the vehicle easier; on the other hand, in very hard snow, the snow may support a vehicle with little or no sinkage on the first pass but repetitive traffic may reduce the hard bonded snow to a loose mass, resulting in a decrease in vehicle performance because of an increase in sinkage and a decrease in traction.

XIV. VARIATIONS IN SNOW PROPERTIES

26. As noted in section VIII, the tests in Greenland were conducted in fine- and coarse-grained snows whose basic behavior patterns were modified by various combinations of hardness and wetness. Variations in physical snow properties were quite large. Some of these variations in the physical and trafficability characteristics of the ice-cap snows investigated are discussed in the following paragraphs.

Physical characteristics.

27. *1955 coarse-grained snow.* Coarse-grained snow was encountered in rapidly melting, mature snowpacks. The temperature of the snowpack profile was uniform at 0 C. Daytime air temperature usually remained above freezing, and produced a loose, granular, wet, soft to medium hard snowpack. A man walking sank to his ankles, and sometimes halfway to his knees. Cooler night temperatures and occasional spells of colder weather produced lower temperatures in the surface layer of the snow, which resulted in a dry, very hard surface crust that permitted easy walking. Ice lenses and thin layers of consolidated snow occurred throughout the snow profile. The hard layers and ice lenses created vertical-sampling difficulties and produced large variations in profile strength measurements. Density varied from about 0.40 to 0.55 g per cm^3, and grain size varied from 2 to 6 mm.

1955 fine-grained snow. The characteristics of fine-grained snow varied considerably depending upon the air-temperature regime and metamorphic processes to which the snowpack had been subjected.

In areas where the snowpack was subjected to frequent warm periods, some melting occurred, and the characteristics of the snowpack were similar to those of the wet coarse-grained snow, except that the grain size was smaller and frequency of occurrence and thickness of ice lenses were usually much less. The temperature of the snowpack was uniform at 0 C and wet to a depth of at least 3 or 4 ft. Cooler night temperatures produced lower temperatures in the surface layer, which resulted in a hard surface crust. The crust would support a man walking, but under the warmer daytime temperature, the crust softened, making walking very difficult. A man walking sometimes sank to above his knees. The snow in the top few inches was usually consolidated in structure, dry and hard during the cooler, early morning hours and wet and soft to medium hard during the late morning; at lower depths the snowpack was granular in structure, wet, and soft to medium hard. The dominant grain size ranged from 1.5 to 2.0 mm, and density ranged from 0.40 to 0.50 g per cm^3.

In areas where the snowpack was subjected to an occasional warming period, the top 2 ft of the snowpack was usually dry, semiconsolidated in structure, and ranged in hardness from soft to medium hard prior to the first warming period. The snow temperature decreased with depth from about −4 C at the surface to about −10 C at a depth of 2 ft. Grain size varied from 0.5 to 1.0 mm, and density from 0.30 to 0.36 g per cm^3. During a warming period, the surface foot or so became moist, soft, and isothermal near the freezing point; density and grain size increased somewhat. The free moisture available during this period also penetrated the lower cold layers, causing the thin lenses of hard snow to become ice. Upon the return of colder weather, the upper layer refroze and became hard to very hard, with thin ice lenses scattered throughout the layer. The presence of ice and hard snow layers throughout the profile produced a wide range of profile strength measurements.

In areas where the air temperature remained substantially below freezing at all times, and during periods when little wind occurred, the surface foot of snow was usually soft, loose, and very fine-grained (0.25 to 0.5 mm); and density ranged from 0.12 to 0.20 g per cm^3. The soft snow made walking difficult. The underlying layer of snow to a depth of 2 ft was soft to medium hard and semiconsolidated, grain size ranged from 0.5 to 1.0 mm, and density ranged from 0.20 to 0.30 g per cm^3. The snow temperature during midsummer decreased with depth from about −6 C at the surface to about −12 C at a depth of 2 ft.

1957 fine-grained snow. As stated earlier, the tests conducted in 1957 were limited to one location (mile 30). At the beginning of the test program, the top 2 ft of the snowpack was medium hard and dry, the temperature of this layer ranged from −20 to −25 C, density ranged from 0.30 to 0.35 g per cm^3, and grain size from 0.25 to 0.5 mm. The snow surface was rough as a result of erosion by the strong winter winds; however, a decrease in wind velocities and subsequent new snows produced a new, smooth snow surface. The previous year's accumulation of new snow was approximately 70 in. The advent of warmer weather produced an increase in the temperature of the snowpack, density, grain size, wetness, and frequency of occurrence and thickness of ice lenses; hardness changed from medium hard to soft; and melting reduced the previous year's accumulation of new snow to about 48 in. at the end of the test period. At the end of the test period, the predominant grain size was less than 2.0 mm with crystal sizes varying from 1.0 to 4.0 mm, density had increased to 0.50 g per cm^3, temperature of the snow was isothermal at 0 C, the snow was wet, and the hardness classification had changed to very soft to soft. During the period of wet snow, a man walking over virgin snow frequently would sink one leg to the hip.

Remolding effects.

28. Wet, coarse-grained snow compacted easily, and its strength always increased with compaction. The increase in strength was proportional to the compaction which could be produced. In general, very coarse and firm snow did not compact as easily as soft, fine-grained snow, which resulted in smaller percentages of strength increases for the former.

The compaction of loose, dry snow and soft, moist or wet fine-grained snow always resulted in strength gains. The loose, dry snow compacted more than moist or wet snow, but the latter two types of snow showed the highest strength after compaction. Hard to very hard snow had a very firm structure caused by the frozen bonds between the individual snow grains. Compaction of this type of snow broke up the bonded structure, reducing the snow to a loose, sugary mass, and thus causing a slight decrease in strength.

Age-hardening.

29. In areas where the snow temperature remained below freezing, the strength of the compacted snow in the vehicle ruts increased with time. The net effect of this phenomenon appeared to be dependent upon the amount of increase in density and the change in snow temperature which followed. In the densified snow layers, the increase in the number of bonds that formed between the individual snow grains apparently resulted in a proportional increase in strength. With time, the strength of the individual bonds increased. If the snow temperature decreased quickly following compaction, these processes were speeded up and the ultimate strength was much higher than if little or no temperature change occurred. Age-hardening of the compacted snow always improved trafficability.

XV. ACTION OF VEHICLES IN SNOW

Development of ruts.

30. The major portion of the ruts created by all the vehicles tested occurred on the first pass, and the ruts slowly deepened with additional traffic. In all cases the ruts were formed by compaction of the snow underneath the track or wheel, and the rut walls always remained vertical, thus indicating little or no lateral movement of the snow. The ruts made were uniform in depth, although occasionally shallow ridges and swales were noticeable after 10 passes. The depth of the ruts formed was, in general, dependent on the initial strength of the snow.

Immobilizations.

31. Immobilizations experienced in previous Greenland tests were usually the result of excessive sinkage on the first pass or were caused by ridges and swales (waves) that developed along a rut surface with continued traffic (greater than 40 passes). First-pass immobilizations were experienced only by conventional wheeled vehicles, whereas all vehicles, regardless of contact pressures, were susceptible to immobilization as a result of waves caused by repetitive traffic. Inadequate bearing and traction capacities were not important factors in repetitive-traffic immobilization. Therefore, since excessive ridges and swales were produced by large numbers of passes and since it is not necessary to apply large numbers of passes in the same ruts because of the expanse of the ice cap, traffic for the tests reported herein was limited to 10 passes. With 10-pass traffic or less, wave development was not significant; therefore, it is not discussed in this report. The results of wave formation with 40- to 50-pass traffic were described in Report 2 of this series.

In soft to medium hard, wet or moist coarse-grained snow, traffic was difficult but possible

with conventional wheeled vehicles when the rut depth did not exceed the clearance of the vehicle. However, as soon as the undercarriage started to drag, the vehicle began plowing (Fig. 18), uneven ruts formed as a result of slippage, and immediate immobilization occurred. In the portion of the test

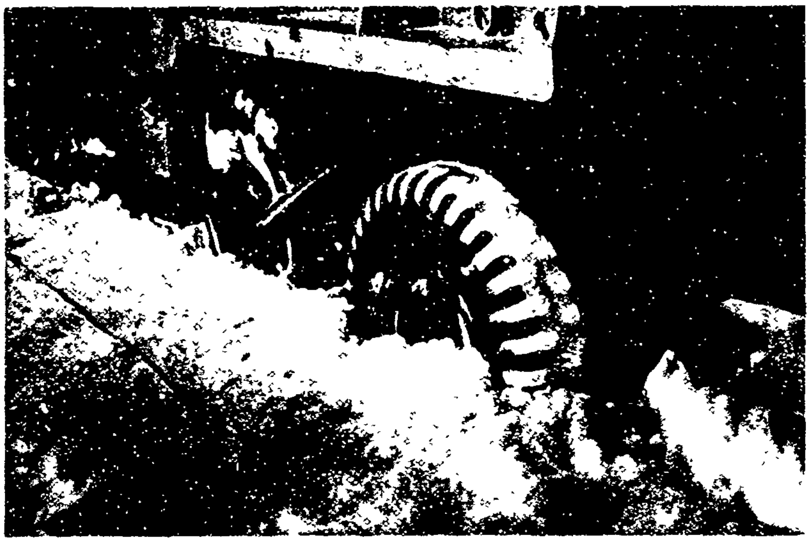


Figure 18. 2-1/2-ton truck M47 immobilized in wet coarse-grained snow at mile 7.

lane where one pass was completed, successive passes could be made with ease, but the vehicle was subject to immobilization because of irregular rutting or slipperiness on the hard, icy rut surface that developed as a result of traffic. Variation in tire pressures had little or no apparent effect on sinkage, although at low tire pressures (10 psi) traction increased and going was easier. In general, tracked vehicles negotiated these snows with ease. However, during the peak of the melt period, local deposits of very large, wet snow crystals made going somewhat difficult for the tracked vehicles because these large crystals acted like "greased marbles" when wet, causing excessive sinkage and minimum traction because they were easily displaced by the vehicle track. Extensive maneuvering with such vehicles as the otter was not possible without immobilization occurring. While traveling over saturated snows, tracked vehicles were also susceptible to immobilizations because of the combined effects of sinkage and lack of traction. Only tracked vehicles were tested in wet fine-grained snow. These vehicles made comparatively deep ruts but performance was good. However, because of the deep ruts, maneuvering was somewhat difficult.

Moist, soft, fine-grained snow overlying soft to medium hard, dry snow was capable of supporting the empty and loaded (5000 lb) 2-1/2-ton truck at 10-psi tire pressure. Sinkage was not excessive (9-in. ruts), going was easy, and maneuvering was possible. Deep ruts formed in occasional weak spots, but the truck was able to negotiate them without difficulty. Other rubber-tired vehicles were not tested in this snow condition. It is believed, however, that the snow would have supported the Tournadozer at low tire pressures. Tracked vehicles experienced their easiest going over this type of snow.

Traffic by conventional wheeled vehicles was impossible in soft or hard to medium hard, dry, fine-grained snow because of excessive first-pass sinkage. The specially designed rubber-tired Terracruiser also became immobilized on the first pass when crossing a soft spot and occasionally while making a turn. While turning, one of the bags or tires would start slipping and even though all the bags were powered, slippage of one bag would result in all the power being transmitted to this bag, thus terminating the forward motion of the vehicle. A power-distribution system that would maintain

power on all bags at all times, or even decrease the power transmitted to a bag once it starts slipping, would materially improve the mobility of this vehicle. Whenever the forward progress of the Terra-cruiser was reduced to zero in a turning maneuver, it could be backed up and then could proceed forward along a straight-line path. Tracked vehicles had no difficulties in negotiating these snows.

PART IV. ANALYSIS OF DATA

32. As stated earlier, the specific objectives of this test program were (a) to correlate the performance of self-propelled and towed vehicles with snow-property measurements, and (b) to select an instrument that can be used to measure snow trafficability and yet meet the military specifications of simplicity, light weight, portability, speed of readings, etc. Another primary objective of the test program was to distinguish snow conditions that permit a vehicle to travel from those that do not. Unfortunately, since snow conditions that did not permit travel were not encountered during the 1955 and 1957 field programs, this latter objective could not be met. However, two important criteria of vehicle performance that were measured, the depth of rut created by one pass of the vehicle and the maximum drawbar load the vehicle could tow, constitute parameters whose variation with snow condition can be studied. Also, towed tests were included in the Greenland program to study the variation of static and kinetic pulls required to tow sleds and a tracked trailer with changes in snow condition.

XVI. METHOD OF ANALYSIS

33. The analysis presented herein consists of a study of the plots of rut depths and towing abilities (for self-propelled vehicles) and static and kinetic pulls (for sleds and a tracked trailer) versus various average measurements of snow strength, snow density, and temperature. Grain-size and wetness characteristics of the snow are indicated for each point plotted. Where there was a variation in grain size and wetness in a particular layer of snow being considered, the predominant grain size and wetness were assigned to that layer. The best correlations usually were obtained when the snow conditions were separated into classes on the basis of wetness. For the before-traffic snow property-rut depth correlations, wetness was separated into two classes: dry and moist, and wet; for the towing and towed tests, snow wetness is considered as dry, moist, and wet. Because of the short period during which moist snow was encountered, the number of tests conducted in this snow type was limited. In some cases, the data were not numerous enough or were too erratic to permit drawing separate curves for the different snow classes, in these cases one curve was drawn for all snow classes.

Average data for the entire length of the test lane in each test are used in this analysis. In processing the voluminous field data to determine average data, the individual field values of strength (cone index, vane shear, Canadian hardness, etc.) that were unusually high, and thus not representative of the average data, were not used. These high values were the result of measurements made in or through a thin ice lens or a compacted lens of snow. Experience in Greenland in 1954 indicated that thin ice lenses or thin, compacted snow layers contributed little or nothing to the support of a vehicle. At the wet, coarse-grained snow test sites (miles 0, 7, 8, and 32) tests were run in areas that contained heavy ice lenses at frequent intervals within the snow profile; consequently, most of the snow measurements resulted in high readings, making the average for the tests comparatively high for this snow type. An example of the field data collected and the data that were ruled out in the averaging process are shown in Table 4.

In the 1954 Greenland studies, it appeared that the best correlations for depth of rut made by the lightweight vehicles and for sliding friction versus snow-property measurements were obtained when average data for the top 6 in. of the snow profile were considered; the best correlations between

rut depth and snow-property measurements for vehicles weighing more than 10,000 lb were obtained when average data for the top 12 in. of the snow profile were considered. These findings also appear to hold true in the analysis of 1955 and 1957 data except that in the towing tests, the best correlations were obtained when data for the top 12 in. were used for all vehicles regardless of weight, and when snow wetness was separated into the usual three classes, dry, moist, and wet.

The drop-cone, torque tube, and variable-load shear vane readings were taken with the instrument dropped or placed on the surface of the snow. Since these instruments were used with different weights, the depths to which they sank were dependent upon the weights used and the strength of the snow. Shear strength values used in the analysis for the torque tube and variable-load shear vane were read from the shear strength vs load curves at the loading corresponding to the nominal ground-contact pressure for the vehicle under consideration. Examples of these data plots are given in Plate 4 and discussed in "Comparison of measured and computed vehicle towing performance," page 46.

Most of the curves on the data plots to be discussed in this analysis of data represent visual averages of the data shown. Where applicable, data from the 1954 Greenland tests were also considered in drawing the curves. In many cases insufficient or widely scattered data made it difficult to place a curve properly. In such cases the location of the curve was influenced by some of the better-defined curves.

In the following paragraphs the test data are analyzed under four headings: Self-Propelled Tests, Tracked Vehicles; Self-Propelled Tests, Wheeled Vehicles; Towing Tests, Tracked Vehicles; and Towed Tests.

XVII. SELF-PROPELLED TESTS, TRACKED VEHICLES

34. In 1955, 48 self-propelled tests were run with five tracked vehicles, and in 1957, 76 self-propelled tests were run with eight tracked vehicles towing no load and traveling a straight-line path over level virgin snow. Summaries of the results of these tests are contained in Tables 5-8. Tables 5 and 7 contain data for the tests of the lightweight vehicles, conducted in 1955 and 1957, respectively; results of tests of vehicles weighing more than 10,000 lb, conducted in 1955 and 1957, are shown in Tables 6 and 8, respectively. All data in these tables are listed in the order of increasing test vehicle weight. Tables 5 and 7 present data for 22 weasel M29C tests, 13 Sno-Cat 743 tests, and 18 otter M76 tests. Tables 6 and 8 present data for 26 D6 tractor, 9 LGP-D7 tractor, 9 hi-speed tractor M5A4, 12 hi-speed tractor M4, 5 LGP-D8 tractor, and 10 medium tank M48 tests.

Correlation of first-pass rut depth with before-traffic data.

35. The depth of rut created by the first pass of a tracked vehicle was plotted against an average value of a snow property as measured by each of several instruments before traffic was applied. Plates 5-16 show rut depth after one pass versus each of the following 12 snow-property measurements: cone index, compaction in remolding cylinder, rating cone index, initial vane shear strength, residual vane shear strength, Ramm hardness number, Canadian hardness, 2-1/4-in. torque tube initial shear strength, 2-1/4-in. torque tube residual shear strength, drop-cone hardness, density, and snow temperature. These plots are discussed in the subsequent paragraphs.

Comparison by snow-property measurements. A study of plates 5-15 shows that as snow strength and density increased, depth of rut decreased, and as compaction in inches in the remolding cylinder decreased, depth of rutting decreased for both snow classes, except that no wet snow curves were drawn

for density (Plate 15). For wet snow, no relation was apparent between snow density and the depth of rut formed. No curves were drawn on the snow temperature plot, Plate 16, because there appears to be little or no relation between snow temperature and the depth of rut that a given vehicle may form.

Comparison by vehicles. Curves taken from Plates 5-15 are grouped according to abscissa (snow property) for each of the two snow classes in Plate 17, sheets 1-3. These curves show that under the same snow conditions, the rut depth increased as the nominal contact pressure of the vehicle increased. However, in a few instances the data on the individual plots were very limited, and in several cases the curves were drawn to fit the family of curves rather than the data.

Comparison by snow class. Ruts in wet snows were deeper than ruts in dry or moist snows that had the same snow-property reading. This can be seen by an inspection of Plate 17, sheets 1-3. It can also be noted that the spread between rut-depth curves for the two snow classes usually increased as the nominal contact pressure of the vehicle increased.

Measure of quality of plots. The final positions of the various rut-depth curves were the result of a combination of trying to fit them to the plotted data and at the same time trying to maintain a general similarity of shape for all curves with the same abscissa. The curves therefore were to a significant extent based on the judgment of the analyst. In order to evaluate the quality of such curves objectively, and in the process determine a comparison of the ability of the various snow properties (abscissae) in predicting rut depth, the following method of measuring the "quality" of the plots was devised (see Table 9):

a. First, determination was made of the difference (or deviation) in rut depth between each plotted point and its respective curve at the same abscissa value.

b. These deviations were then averaged without regard to sign. They are shown as "Average deviation, in." under each vehicle and snow class in Table 9. The numbers of readings used in the average and rut-depth range also are shown.

c. The number of plotted points for each vehicle and snow class was small in some cases. In order to have a larger number of points as a basis for conclusions concerning the quality of a given abscissa in predicting rut depth, groups of vehicles and snow classes were considered. For each point the deviation was divided by its corresponding rut-depth value from the curve and termed "Per cent error." These values were then numerically averaged for each data plot. A weighted per cent error average was computed for the three vehicles weighing less than 10,000 lb, the six vehicles weighing more than 10,000 lb, and all nine vehicles by multiplying the average per cent error for each curve by the number of points used in the curve, adding these products, and dividing by the total number of points in the group of curves being considered. This was done for curves for both snow classes. The per cent errors for all vehicles weighing less than 10,000 lb, all vehicles weighing more than 10,000 lb, and all vehicles and both snow classes are also shown in Table 9.

Evaluation of quality of plots. A summary, expressed as weighted averages, of the average deviation in rut depth and per cent error determined for each snow property, vehicle, and snow class (see Table 9) is given on the following page.

Snow Property	No. of Readings		Average Rut Deviations, in.			Per Cent Error
	Dry and Moist Snow	Wet Snow	Dry and Moist Snow	Wet Snow	Both Snow Classes	Both Snow Classes
Cone index	83	41	0.53	0.63	0.56	13.2
Compaction in remolding cylinder	59	28	0.39	1.52	0.76	23.0
Rating cone index	60	28	1.69	1.18	1.53	45.1
Initial vane shear	83	27	0.55	0.89	0.63	18.5
Residual vane shear	83	27	0.89	2.28	1.23	28.5
Ramm hardness number	50	28	0.57	0.98	0.72	22.5
Canadian hardness number	49	28	0.88	1.01	0.92	26.0
2-1/4-in. torque tube initial shear	22	10	0.93	0.58	0.83	19.6
2-1/4-in. torque tube residual shear	23	10	0.89	0.41	0.75	20.3
Drop-cone hardness	20	15	0.45	0.55	0.49	12.4
Density	83	—	0.65	—	0.65	26.7*
Average			0.77	1.00	0.82	23.3

* Dry and moist snow only.

The preceding tabulation shows that the before-traffic snow-property measurements listed were capable of predicting the first-pass rut depth created by all the tracked vehicles tested to within an average of less than ±1 in. or within an average per cent error of 23.3. The average deviations were larger for the wet snow class than for the dry-moist class. Drop-cone hardness and cone index gave the best accuracy (per cent errors of 12.4 and 13.2, respectively), and rating cone index and residual vane shear gave the worst (45.1 and 28.5 per cent errors, respectively).

Correlation of one-pass snow-property data with rut depth.

36. A graphical analysis similar to the before-traffic snow-property measurements versus rut depth was made with average one-pass data for several snow measurements. The data plots are shown in Plates 18-20 and include cone index, initial vane shear strength, and density.

An examination of the data plots reveals that the data are somewhat scattered and that no consistent relations are apparent between one-pass snow measurements and rut depth. The predominant trend, however, appears to be that for each wetness snow class a vehicle has a tendency to compact the snow to approximately the same snow-property value, regardless of the amount of compaction or rutting. This trend is quite clearly identified for the wet snow class where deep ruts were formed, and for dry snow in Figure 5 of Plates 18-20, where comparatively more data are available from tests conducted with the standard D6 tractor. Average values are shown for each vehicle and wetness class in each figure.

Most of the variation in after-traffic strength data that occurs in dry snow can be attributed to the age-hardening of the snow. The amount of variation is dependent on the elapsed time between the formation of the ruts and the completion of data collection, and on snow temperature. In the wet coarse-grained snow, most of the variation in after-traffic snow-property measurements is caused by ice lens fragments mixed within the snowpack; in some cases, heavy ice lenses provided support to the vehicle, resulting in shallower ruts and hence less change in snow-property measurements.

Comparison of one-pass snow-property data
by vehicle and snow-wetness class.

37. The average values of snow-property measurements obtained after one pass of each vehicle in each snow-wetness class, shown in Plates 18-20, are summarized in the following tabulation.

Vehicle	Ground-Contact Pressure, psi	Average One-Pass Data: Cone Index, Dry	Cone Index, Moist	Cone Index, Wet	Initial Vane Shear Strength, psi, Dry	Vane Shear, Moist	Vane Shear, Wet	Density, g/cm^3, Dry	Density, Moist	Density, Wet
					0- to 6-in. Depth					
Sno-Cat	1.02	12	—	25	2.1	—	3.2	0.34	—	0.59
M29C	1.68	13	25	25	2.2	3.7	3.2	0.36	0.46	0.58
M76	1.72	20	47	54	2.8	3.8	5.5	0.42	0.50	0.59
					0- to 12-in. Depth					
LGP-D7	2.89	28	74	68	2.1	6.8	8.4	0.44	0.48	0.51
D6	3.17	30	57	63	3.0	5.2	8.1	0.42	0.54	0.61
LGP-D8	3.59	30	—	61	2.8	—	—	0.46	—	0.65
M5A4	6.37	38	—	85	2.6	—	—	0.47	—	0.66
M4	7.02	37	—	88	2.8	—	7.7	0.48	—	0.62
M48	10.50	52	—	137	3.5	—	—	0.49	—	0.66

These average one-pass values for each wetness class are plotted against ground-contact pressure in Plate 21, and summary curves are shown in Plate 22. From the summary curves it can be seen that after one-pass traffic, the lowest values in snow-property measurements occurred in dry snow, followed by those in moist and wet snow, respectively. The strength curves for the moist and wet snow are identical for ground-contact pressures less than about 2 psi, and begin to diverge at ground-contact pressures greater than about 2 psi. The rates at which strength changes as a result of increase in ground-contact pressure are greater in the moist and wet snow than in the dry snow. The density curves, however, are parallel and distinct for each class of snow wetness. The rate of change in density also decreases at ground-contact pressures greater than about 3 psi.

After-traffic data.

38. The data collected after one and 10 passes, respectively, were examined to determine the effects of repetitive traffic on snow trafficability. The items considered were rutting and strength changes that occurred as a result of compaction by vehicular traffic. The rut depth serves as an indicator of trafficability of the snow, and the strength changes that occurred after traffic reflect the strength available for vehicle support and traction. The results of these findings are described in the following paragraphs.

Rutting. The [illegible] of repetitive traffic on rut-depth development by a weasel M29C and a standard D6 tractor with [illegible] in. track width is illustrated in Figure 3 of Plates 23-25 for three conditions of snow wetness. It can be seen that, in all cases, the majority of the total rutting occurred on the first pass with slow progressive deepening on each pass thereafter. Although deep ruts usually produce difficult going because of increased rolling resistance, none of the tracked vehicles tested experienced any difficulties in negotiating the first pass.

Strength changes with depth. Typical curves showing the change in strength, as measured by the cone penetrometer, that occurred with depth after 1- and 10-pass traffic by a weasel M29C and

D6 tractor are shown in Figures 1 and 2 of Plates 23-25. The values plotted are average cone indexes for the entire test lane, and the symbols used in plotting the 0-pass curves designate the snow type. Ice lenses present in the snow profile are not shown in the data plots.

From an examination of the 0-pass strength curves, it can be seen that the various snow types exhibit distinct strength profiles. The wet coarse-grained snow shows little change in strength with depth except for a soft surface layer. In the moist fine-grained snow, the strength increases with depth for about 10 in., changes little for the next 8 in., and then increases with depth in the underlying dry snow. The dry fine-grained snow strength curves show that the top 12 in. of snow is soft; however, below this depth the strength increases rapidly with depth.

Repetitive traffic on the different snow types also resulted in somewhat different strength patterns. In the wet and moist snow the weasel M29C created a shallow rut on the first pass, and the strength increased slightly to a depth of about 10 in. After 10 passes the rut depths in both snow conditions had increased slightly, but strength gains in the top few inches were comparatively large. In the dry, soft snow the weasel M29C made an appreciable rut on the first pass and strength increased to a depth of about 15 in. below the original surface, reaching its peak about 3 in. below the rut surface. Following 10-pass traffic, the rut depth had increased 1 in.; however, little change in strength occurred except for the reading 3 in. below the rut surface (10 in. below original depth). The strength changes that took place under the track of the heavier D6 tractor were more pronounced. In the wet snow, appreciable ruts were made on the first pass and strength increased with depth to about 40 in. below the original surface. The maximum strength changes took place in the middle of the compacted layer. Ten passes increased the rut depths a few inches. The depth of the compacted layer remained about the same, but strength continued to increase significantly from the surface to about 10 in. below the rut surface. In the moist snow the ruts produced on the first pass were comparatively shallow, but a large strength increase occurred in the moist snow layer with the maximum occurring about 3 in. below the rut surface. Strength increases extended to a depth of about 15 in. below the surface. After 10 passes the ruts had deepened slightly, strength continued to increase with depth, and large gains in strength were made in the top layer. In the dry snow, the D6 tractor rutted about 8 in. on the first pass and strength increases extended to about 25 in. below the original surface. Following 10-pass traffic, the ruts had increased several inches and strength continued to increase with depth, reaching a maximum 6 in. below the rut surface. No noticeable strength change occurred in the surface layer.

Stress patterns. The stress patterns that resulted from compaction by a vehicle traveling over virgin snow were defined for most of the vehicles tested after one-pass traffic for the three classes of snow wetness, using the "pit-burning" technique developed by Dr. Ukichiro Nakaya. Attempts were made to obtain similar patterns after repetitive traffic, but the patterns were somewhat distorted because the vehicle usually could not follow the same track without overlapping the rut walls. The patterns were obtained by digging a pit across one rut and setting off a gasoline bonfire in it. The virgin snow melts more rapidly than the compacted snow, and the individual snow grains of the compacted snow accumulate more carbon than the virgin snow. These effects, plus the natural, stratified differences in snow properties in the snowpack, result in a readily visible pattern showing the effect of the vehicle on the snow. Examples of these patterns for several vehicles are shown in Plate 26, sheets 1-6.

Snow-property data were also collected alongside the pits excavated. A summary of these data is given in Table 10. Several plots were made from the data given in Table 10 to determine the effects of gross vehicle weight and ground-contact pressure on characteristics of the stress bulb formed, and changes in strength (as measured with the cone penetrometer) and density which occurred in the stress bulb after one-pass traffic. The results are discussed in the following paragraphs.

The depth to the bottom of the stress bulb from the virgin snow surface was plotted against average before-traffic cone index for the same layer (Plate 27). The curves drawn indicate that for a given vehicle the depth to the bottom of the stress bulb decreased as cone index of the virgin snow increased. Apparently the perimeter of the stress bulb (Plate 26) defines a locus of points at which the stress induced is equal to the snow strength. A plot of depth to bottom of bulb versus vehicle weight at a cone index of 10 (Plate 28) shows that the depth to the bottom of the stress bulb increases in a regular pattern as vehicle weight increases.

The effect of ground-contact pressure on strength and density changes after one-pass traffic for dry snow is shown in Figures 1 and 2, respectively, of Plate 29. In each case the abscissa represents the changes which occurred between 0- and 1-pass traffic and was obtained by dividing the one-pass data by the before-traffic data given in Table 10. Where several sets of data are shown for the same snow wetness, averages were plotted. It can be seen from Plate 29 that as ground-contact pressure increases, the change in cone index and density produced by the first pass of the vehicle also increases. The change in density with an increase in ground-contact pressure is fairly uniform for the entire range of data presented, but the rate of strength change begins to drop off sharply at about 8-psi ground-contact pressure. This may indicate that for compaction purposes, the maximum strength gain may be obtained by vehicles similar to those tested in this program with contact pressures in the order of 8 psi.

Another aspect of the change in the snow produced by traffic is obtained by dividing the thickness of the stress bulb by the depth from the snow surface to the bottom of the stress bulb. These data are shown in column 5 of Table 10, and plots for each snow type and summary curves are shown in Plate 30. The data show that the ratio decreases as ground-contact pressure increases, but the rate of change decreases at the higher ground pressures. The ratio difference may account for the increase in snow-property change with an increase in ground-contact pressure. The summary curves in Figure 4, Plate 30, show that the difference in the curves due to snow wetness is small. Usually as snow wetness increases, strength decreases, and rutting increases accordingly, however, the ratio between stress bulb thickness and depth from snow surface to the bottom of the stress bulb remains fairly constant.

Remolding. Cone index data taken after traffic were also compared with the before-traffic data to determine the amount of remolding that occurred in the critical layer, and to determine whether or not the remolding index determined in the remolding cylinder adequately reflected the remolding effects that occurred as a result of 1- and 10-pass traffic. Average data were compiled from the data given in Tables 5-8 for each vehicle and each snow wetness class. Table 11 presents the results of these computations.

The data presented in Table 11 indicate that strength had increased after 1- and 10-pass traffic, respectively, for all snow conditions and vehicles tested. The ratio of strength increase, expressed as vehicle compaction strength index (columns 6 and 7, Table 11), varied with vehicle contact pressure, snow wetness, and the amount of traffic applied. A study of data plots (not shown) comparing remolding index and compaction strength index for 1- and 10-pass traffic revealed that the data were widely scattered and that only general relations were apparent, thus indicating poor agreement between remolding and vehicle compaction indexes. The wide variations can probably be attributed to the difficulties encountered in attempts to measure accurately the strength of the compacted sample in the remolding cylinder because the sample usually fractured as soon as the cone penetrometer entered it. This was particularly true for the soft, dry fine-grained snows. Ice lenses in the moist and wet snow samples had a greater effect on the initial readings than on the after-compaction readings, causing the remolding index values to be less than those obtained in similar snow that contained no ice lenses. Furthermore, the analysis indicated that in order to improve remolding index and hence

rating cone index relations, the number of blows required should be varied according to snow type, initial strength of the snow, and type of vehicle.

Compaction characteristics.

39. A comparison of the compaction characteristics representative of the surface 10.8 in. of snow types tested was made, and the results are given in Plate 31. The plots show the change in cone index (Fig. 1), density (Fig. 2), and compaction in inches (Fig. 3) which occurred by varying the compaction effort on the same sample. The size of the mold and drop hammer was the same as that used in the remolding tests. It is to be noted that the maximum amount of change in density and compaction occurred during the first 15 blows or less, with gradual changes occurring thereafter. Figure 1 shows that substantial strength increases occurred with increased compaction effort for the moist and wet snows regardless of grain size. Compaction of the moist fine-grained snow resulted in the greatest strength gain (curve 1). The initial strength of the soft, dry fine-grained snow was very small, but steady increases in strength took place with an increase in compaction effort (curve 6). The dry, hard fine-grained snow shows a fairly high initial strength; however, the compaction which occurred after the first few blows destroyed the frozen bonds between the snow grains, and resulted in a decrease in strength (curve 5). With an increase in the number of blows applied and hence an increase in compaction, a strength increase occurred which affected the initial loss of strength at the beginning of the compaction cycle. With time, age-hardening will result in a further strength increase in dry snow.

Comparison of vehicle cone index
and after-traffic cone index.

40. The vehicle cone index for each vehicle, determined from the empirical mobility index equation and conversion curve developed for soils (Waterways Experiment Station Technical Memorandum No. 3-240, 9th Supplement), was plotted against the average 1- and 10-pass cone index values given in columns 4 and 5, Table 11. The vehicle cone indexes and the data plots are shown in Plate 32.

Since a straight-line relation appeared to satisfy best the data plotted in Figures 1-6 of Plate 32, the line was placed by statistical methods. Linear regression equations, correlation coefficients, and standard deviations are given in each of these figures. All of the correlation coefficients were significant to the 1 per cent level, and they ranged from 0.84 to 0.96.

An examination of the plots in Figures 1-6 of Plate 32 shows that in general the after-traffic cone index varied directly with the vehicle cone index; but the rate of variation was dependent on the wetness of the snow and the number of passes. The tabulation below shows the variation rates (slopes of the six straight-line curves).

	Variation Rates		
No. of Passes	Dry Snow	Moist Snow	Wet Snow
1	0.82	0.32	0.30
10	0.31	0.17	0.08

Generally speaking, the after-traffic cone index could be estimated by multiplying the vehicle cone index by the appropriate figure shown in the preceding tabulation and adding 15.

XVIII. SELF-PROPELLED TESTS, WHEELED VEHICLES

Scope.

41. The tests conducted in 1955 with self-propelled wheeled vehicles were limited in number because the mobility of conventional wheeled vehicles in the Greenland snow was very poor, and two of the three vehicles tested were available for test on only one snow condition. The 2-1/2-ton truck M47 mounted with 11.00-20 high-flotation tires, however, was available for testing during the entire test period, and tests of this vehicle were run in moist and wet snow at several tire pressures and loads. No tests were run in soft, dry snow since the vehicle became immobilized immediately upon leaving a hard compacted area. Because of the limited number of tests, a separate analysis is presented herein for the 2-1/2-ton truck M47.

Data used in the analysis are summarized in Table 12, which includes data obtained from six 2-1/2-ton truck M47 tests, one Tournadozer test, and three Terracruiser XM357 tests.

Vehicle-performance correlations.

42. The ability of snow-property measurements (cone index, compaction in remolding cylinder, rating cone index, vane shear readings, Ramm hardness number, Canadian hardness, and density) to evaluate the performance of wheeled vehicles was determined by comparing average before-and after-traffic data with the performance of the 2-1/2-ton truck. Only first-pass vehicle performance was considered in the analysis since the vehicle could travel easily in its compacted ruts. Rut depth was also considered as a measure of vehicle performance. All 2-1/2-ton truck M47 tests listed in Table 12 were conducted at 10-psi tire pressure except item 52, which was run at 40-psi tire pressure.

Comparison by snow-property measurements. Before-traffic and one-pass data plots are shown in Plate 33. After an examination of the plotted data, an attempt was made to separate the immobilizations from the nonimmobilizations by drawing a horizontal line; however, no consistent relations were apparent. Comparison of average measurements for depths other than the 0- to 12-in. depth were also made, but similarly inconclusive results were obtained.

The reason for the inability to separate immobilizations from nonimmobilizations by means of the snow-property measurements can partially be explained by the fact that snow type must be considered along with snow-property measurements; and since sufficient data were not available, the effects of snow type could not be shown. This fact was evident in the rut depth versus strength analysis of results of self-propelled tracked vehicle tests where more complete data showed that similar strength values were obtained in different snow types, but yet rut depths varied.

Rut depth versus before-traffic and one-pass data. The effects of rut depth on vehicle performance and the ability to predict rut depth from several snow strength measurements (cone index, Ramm hardness number, and initial vane shear strength) made before and after one pass were determined from an analysis of the plotted data shown in Plates 34 and 35. Figure 1 of Plate 34 indicates that a line can be drawn separating immobilizations from nonimmobilizations on the basis of rut depth. The critical rut depth for both snow types shown was estimated to be 11 in. At rut depths greater than 11 in. the bottoming and plowing actions of the vehicle developed additional resistance which contributed to the immobilization. It is to be noted that the separation line also divides the snow types tested; deep ruts were formed in the wet coarse-grained snow, and comparatively shallow ruts were formed in the moist fine-grained snow. On the basis of other vehicle performances, soft, dry fine-grained snow data would plot somewhat above the area occupied by the wet coarse-grained snow. The results of correlations obtained between rut depth and snow strength measurements made

before traffic are presented in Figures 2, 3, and 4 of Plate 34, and similar correlations for one-pass strength data are shown in Plate 35. These plots show that rut depth after one pass correlates reasonably well with before-traffic data; but the strength measurements after one pass are rather similar regardless of rut depth. Averages for the data are shown as vertical lines on the plots in Plate 35.

Effects of tire pressure and load. During the test program, several attempts were made to determine the effects of tire pressure and load on the mobility of the 2-1/2-ton truck M47. In the wet coarse-grained snow at mile 7 (test site B), tests were run with tires inflated to 40-, 20-, and 10-psi pressures. The results of these tests indicated that the mobility of the truck was not materially improved until the tire pressure was reduced to 10 psi. The vehicle could travel 15 ft on virgin snow at 40-psi, 20 ft at 20-psi, and 50 ft at 10-psi tire pressure. During these tests differences in rut depths were not apparent. At mile 60 (site F) also, reduced tire pressure improved the mobility of the 2-1/2-ton truck M47. Although rutting was similar at 20- and 10-psi tire pressures, the improved traction at 10 psi permitted the truck to negotiate soft spots with ease, whereas immobilizations were occurring at 40-psi tire pressure. Several load tests (1000- and 5000-lb) were also run at mile 60 at 10-psi tire pressure, and only small differences in rut depth were apparent.

XIX. TOWING TESTS, TRACKED VEHICLES

43. The objective of the towing data analysis was to determine the relation between the maximum drawbar pull that a tracked vehicle could develop on the first pass and before- and after-traffic snow-property measurements. Towed tests were also conducted to determine the resistance offered by a vehicle when towed over various snow surfaces. All tests were conducted on level snow with the vehicles traveling at a speed of approximately 2 mph.

A total of 83 towing tests were conducted during the 1955 and 1957 test programs. Twenty-three drawbar pull-slip tests were run with four vehicles in 1955, and 60 towing tests were run with seven vehicles in 1957, of which 38 were drawbar pull-slip tests and 22 maximum drawbar pull tests without slip measurements. Data from these tests are summarized in Tables 13-16. Tables 13 and 15 contain summary data for the tests of the lightweight vehicles conducted in 1955 and 1957, respectively; tests of vehicles weighing more than 10,000 lb, conducted in 1955 and 1957, are shown in Tables 14 and 16, respectively. Tables 13 and 15 present data for 24 weasel M29C and 14 otter M76 tests. Tables 14 and 16 present data for 12 D6 engineer tractor, 8 hi-speed tractor M5A4, 1 LGP-D7 tractor, 10 hi-speed tractor M4, 5 LGP-D8 tractor, and 9 medium tank M48 tests.

Correlation of maximum drawbar pull with before-traffic data.

44. Average before-traffic data were plotted against maximum drawbar pull expressed as tractive coefficient and pull in pounds, and the individual plots were examined for possible correlations. Plates 36-45 show the maximum drawbar pull related to 10 snow-property measurements: cone index, compaction in remolding cylinder, rating cone index, initial vane shear, Ramm hardness number, Canadian hardness, 2-1/4-in. torque tube initial shear, 2-1/4-in. torque tube residual shear, drop-cone hardness, and density. Residual vane shear strength measurements were not used in these correlations because of the narrow range in data. Summary curves are plotted in Plate 46, sheets 1-3. If only one test was conducted in a given snow wetness, the point is not plotted. The results of these correlations are discussed in the following paragraphs.

Comparison by snow-property measurements. A comparison of the data plotted in Plate 46 and the individual snow-property measurements plots in Plates 36-45 reveals that the configuration

of the curves drawn is, in general, similar for all snow-property measurements. The curves for most of the snow-property measurements are parabolic in form, and drawbar pull increases as magnitude of the snow-property measurements increases until an optimum condition is reached, after which the drawbar pull decreases as the magnitude of the snow-property measurements continues to increase; the best performance was obtained when the vehicles were operating in moist snow. The shape of these drawbar pull curves is different from that of drawbar pull curves established in towing tests of tracked vehicles on fine-grained soils. In soils, as the strength increases the drawbar pull increases rather sharply until the soil becomes too strong to permit penetration of the vehicle's grousers and the curves flatten out.

From a study of the individual plots it can be seen that some of the data are widely scattered and that the relations represented by the curves for some of these plots are rather poor. Furthermore, the range in tractive coefficients is small and even though separate curves are drawn, many plots actually contain only several scattered points. For the wet snow class, a few of the curves drawn are not in agreement with the other snow-property measurements.

Comparison by vehicles. Cone index, initial vane shear, and density measurements are used in this discussion because these measurements were made for all vehicles tested. Summary curves for these measurements are given in Plate 46.

The summary curves show that the correlations are quite similar for all vehicles tested, and differences in vehicle performance are apparent between various types of vehicles and classes of snow wetness. For dry snow the weasel M29C (curve 1) appears to give the best performance throughout the range of snow properties measured, followed by the low-ground-pressure tractors with girderized tracks (curves 3 and 4); next is the otter M76 with large, pneumatic bogies and rubber track (curve 2); and then the high-ground-pressure vehicles (M5A4, M4, and M48) with large, rigid bogies (curves 5, 6, and 7). In moist snow the low-ground-pressure D6 tractor (curve 3) performed best and the weasel M29C (curve 1) next best; the relative order of the remaining vehicles tested cannot be established because of limited test data. In wet snow the LGP-D8 tractor (curve 4) outperformed the other vehicles; the remaining vehicles are fairly closely grouped together in relation to performance in wet snow.

The difference in the performances was as might be expected since the girderized track of the LGP tractors distributes the load underneath the track more uniformly than do the tracks of the other vehicles tested. The reason for the better performance of the weasel M29C in dry snow is not apparent from the data. In soft, moist and wet snow the weasel M29C "heels down," which causes it to be constantly climbing a slight slope during its forward progress, and the rear center section drags, thus reducing its effective towing performance.

The comparatively poor performance of the otter M76 might possibly have been due to its track system, which is a rubber-belt open track with large pneumatic tires for bogies. Since the maximum drawbar pull that a vehicle can develop occurs with some track slippage, the openings in the otter M76 track permit the sheared snow to escape, thus decreasing the effective track area. Undoubtedly, the traction ability of the otter could be increased by closing the track openings.

Evaluation of the quality of plots. For each snow-property measurement, the average deviation in tractive coefficient of the plotted points from their respective curves and the per cent error were determined. The quality of the plots was determined in the same manner as described in "Measure of quality of plots," page 32. The results of these tabulations for each vehicle and snow property are presented in Table 17, and a summary for all vehicles tested is given in the tabulation on the following page. The values shown are weighted averages.

Snow Property	No. of Readings			Average Tractive Coefficient Deviation				Per Cent Error
	Dry Snow	Moist Snow	Wet Snow	Dry Snow	Moist Snow	Wet Snow	All Snow Classes	All Snow Classes
Cone index	42	11	23	0.023	0.027	0.024	0.024	7.4
Compaction in remolding cylinder	28	8	7	0.028	0.031	0.021	0.028	8.6
Rating cone index	28	8	7	0.055	0.072	0.036	0.058	16.4
Initial vane shear	42	8	4	0.038	0.018	0.008	0.032	12.9
Ramm hardness number	29	8	9	0.029	0.079	0.051	0.040	11.3
Canadian hardness	27	8	10	0.060	0.041	0.019	0.048	14.5
2-1/4-in. torque tube initial shear	13	—	4	0.038	—	0.018	0.038	11.4
2-1/4-in. torque tube residual shear	13	—	4	0.043	—	0.025	0.037	11.0
Drop-cone hardness	11	—	4	0.029	—	0.030	0.035	11.8
Density	42	11	19	0.033	0.041	0.029	0.036	11.4
Average				0.038	0.044	0.026	0.038	11.7

The figures in the right-hand column show the accuracy that can be expected when predicting first-pass maximum drawbar pull for the various snow-property measurements. The average per cent error for all snow-property measurements made was 11.7, with cone index giving the best accuracy (7.4 per cent error) and rating cone index the poorest (16.4 per cent error). In terms of average tractive coefficient deviation, the average for all snow-property measurements was 0.038, with a low of 0.024 for cone index and a high of 0.058 for rating cone index. In general, the over-all per cent errors are approximately half the magnitude of the per cent error values determined for rut-depth correlations ("Evaluation of quality of plots," page 32) and the order of correlation of snow-property measurements according to the lowest per cent error is changed.

Comparison of tractive coefficient and ground-contact pressure. Although it is recognized that towing performance will vary with different types of track systems for the same track loading, an estimate of the effects of ground-contact pressure on maximum towing performance on virgin snow can be obtained by plotting tractive coefficients and ground-contact pressures. Plate 47 shows a plot of these two parameters for dry snow with a before-traffic cone index of 20. The tractive coefficient data plotted were obtained from the summary cone index curves in Plate 46 by reading the ordinate value for each of the plotted curves at a constant abscissa value of 20. It can be seen that there is very good agreement between the curve drawn and the data plotted except for the otter M76. Thus, the curve can be used to estimate maximum towing performance. For example, if it is desired to select a vehicle that can tow a load equal to 40 per cent of its weight on a medium to hard dry snow (cone index equals 20), the ground-contact pressure should not exceed about 4 psi.

Correlation of maximum drawbar pull with one-pass data.

45. An analysis similar to the before-traffic snow-property measurements versus tractive coefficient was made with average one-pass data for several snow-property measurements and vehicles. The snow-property measurements were cone index, initial vane shear strength, and density; the vehicles were the weasel M29C, otter M76, and the D6 tractor. The results are shown in Plates 48-50.

An examination of the data plots shown in these plates shows that the data are scattered and that no consistent relations are apparent between tractive coefficient and snow-property measurements. One-pass density measurements show no correlation with tractive coefficient and can probably be best represented by a line drawn vertical to the abscissa, representing an average; average values are shown for each vehicle and snow-wetness class on the density plots (Plate 50). The strength plots for the weasel M29C and D6 tractor, however, show an increase in tractive coefficient with an increase

in strength for dry and moist snow conditions, and a decrease in tractive coefficient with an increase in strength for wet snow. Curves were drawn for the weasel M29C and D6 tractor strength data plots (Plates 48 and 49).

Comparison of snow-property measurements, self-propelled versus towing tests.

46. The data obtained in the self-propelled tests indicated that for each snow-wetness class, one pass of a vehicle over virgin snow compacted it to approximately the same value throughout the test lane. However, towing test results indicated that snow strength increases as drawbar pull increases during one-pass traffic. The reason for this difference is not known. It is suspected that since track slip occurs at maximum drawbar pull, the shearing and kneading action of the snow underneath the track due to slippage may have a tendency to produce a greater strength change.

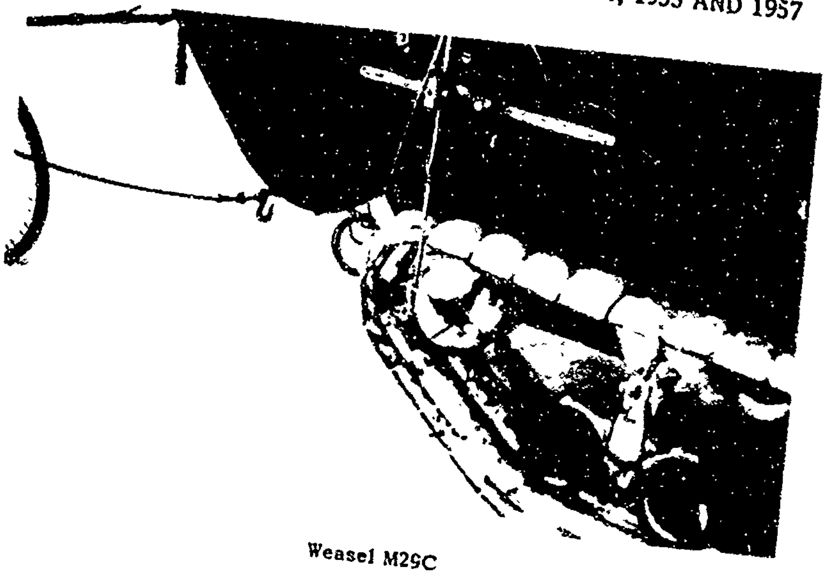
Effects of age-hardening on vehicle performance.

47. *1955 tests.* In 1955, a level area at mile 70 (site G) was compacted with one coverage of the D6 tractor followed by one coverage of the otter M76, and the snow in this area was then permitted to age-harden. After 6 and 30 hr of age-hardening, respectively, towing tests were run with the weasel M29C and D6 tractor. After several hours of age-hardening all vehicles without a tow load could travel over this area without rutting, indicating that bearing capacity was greatly increased by age-hardening. A comparison of first-pass maximum drawbar pull on virgin and age-hardened snow is given in the tabulation below. The air temperature variation during the test period is given in Figure 1 of Plate 51; and a comparison of snow strength, as measured by the cone penetrometer, is shown in Figures 2 and 3 of Plate 51, for virgin snow, after age-hardening, and after one-pass traffic.

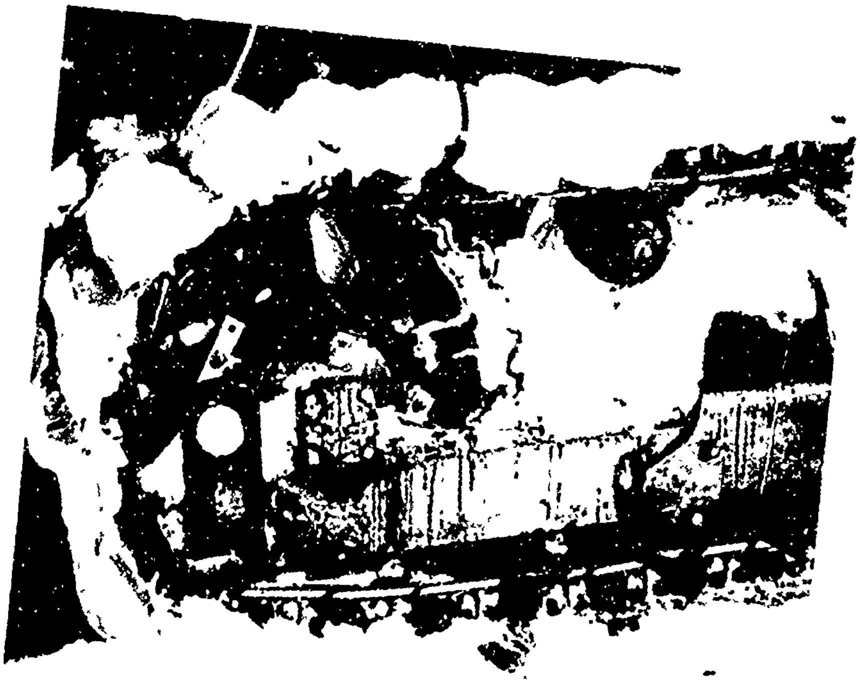
Vehicle	Item No.	Rut Depth in.	Maximum Drawbar Pull lb	Tractive Coefficient
		Virgin Snow		
Weasel M29C	64	3.4	2,200	0.40
D6 tractor	76	6.8	7,000	0.38
		Age-Hardened Snow		
Weasel M29C	65	1.0	2,300	0.43
D6 tractor	77	1.5	11,000	0.60

From this tabulation it can be seen that in the age-hardened area, the tractive coefficient of the weasel was only slightly increased, whereas a large increase occurred for the D6 tractor. The reason for the great improvement in performance of the D6 tractor is not apparent from the data collected. At this test site, snow slabs formed on the pads of the tracks of both vehicles (see Fig. 19); however, this should not account for the difference in vehicle performance.

Figures 2 and 3 of Plate 51 show the profile strength changes that occurred in the age-hardened test lanes. As a result of compaction and age-hardening, the strength in the top 10 in. of snow increased significantly. After 6 and 30 hr of age-hardening, the cone index at the 3-in. depth increased from 4 to 53 and from 2 to 84, respectively. After one pass was applied, track slippage caused a shallow rut to form and the strength of the hard layer was decreased. The strength change under the heavier D6 tractor was greater than that under the weasel M29C. In general, although age-hardening



Weasel M29C



D6 tractor

Figure 19. Snow slabs formed on the pads of the weasel M29C and the D6 tractor.

greatly increases the bearing capacity of the snow, it is believed that traction capacities are not increased correspondingly.

1957 tests. In 1957, several towing tests were conducted on dry and moist snow following the completion of a self-propelled test in which the vehicle had completed 10 passes without a towed load. Vehicles used in these tests were the weasel M29C, otter M76, D6 tractor, and hi-speed tractor M4. For the dry snow tests, age-hardening influenced the strength of the snow because 1/2 to 1 hr was

required to arrange the necessary equipment to conduct a towing test. Following the completion of towing tests on compacted snow, the test was continued on virgin snow. Results of the tests on the virgin and compacted snow are given in Tables 15 (items 173, 177, 185, and 189) and 16 (items 195, 198, 208, and 211). The 11-pass data represent the towing performance on the compacted snow, and the 1-pass data represent the virgin snow run. The 10-pass snow measurement data are those obtained immediately after the completion of the preceding self-propelled test. A comparison of the difference in towing performances on the compacted and virgin snow are given in the following tabulation. Where more than one test was conducted, average values are given.

	Tractive Coefficient			
	Compacted Snow		Virgin Snow	
Vehicle	Dry	Moist	Dry	Moist
Weasel M29C	—	0.44	—	0.42
Otter M76	0.50	—	0.34	—
D6 tractor	0.57	0.69	0.42	0.61
Hi-speed tractor M4	0.39	0.48	0.36	0.41

The tabulation shows that the increase in traction on compacted snow was comparatively small for the weasel M29C and hi-speed tractor M4, but that a significant improvement in performance on compacted snow is apparent for the otter M76 and the D6 tractor. The small improvement in weasel M29C performance on moist, compacted snow agrees closely with the performance improvement obtained on dry, age-hardened snow (described in Paragraph 47); however, the improvement in the performance of the D6 tractor on the dry, age-hardened snow was greater than that shown for the D6 by the preceding tabulation.

Drawbar pull-slip test results.

48. In the majority of the towing tests conducted, track slippage measurements were made for a range of towed loads in order to develop drawbar pull-slip curves for a test run. Drawbar pull and per cent slip for the maximum towing force are shown in Tables 15 and 16. Examples of drawbar pull-slip curves for several vehicles tested on dry snow are shown in Plate 52. The average and range in tractive coefficients and percentage of track slippage developed by the tracked vehicles tested are given below (data taken from Tables 13-16).

		Snow Wetness					
		Dry		Moist		Wet	
Vehicle		Tractive Coefficient	% Slip	Tractive Coefficient	% Slip	Tractive Coefficient	% Slip
M29C	Range	0.26-0.48	15-32	0.33-0.53	16-22	0.31-0.36	11-36
	Avg	0.38	21	0.43	20	0.33	25
M76	Range	0.26-0.37	30-63	0.46	33	0.20-0.36	18-74
	Avg	0.31	49			0.26	39
LGP-D7	Range	0.38	24	—	—	—	—
D6	Range	0.22-0.60	5-28	0.41-0.61	10-12	—	—
	Avg	0.38	17	0.52	11		
LGP-D8	Range	0.38-0.42	29	0.51	17	0.50-0.52	—
	Avg	0.40				0.51	
M5A4	Range	0.25-0.35	28-61	0.29	—	0.26-0.28	10-15
	Avg	0.29	43			0.27	12
M4	Range	0.24-0.36	25-51	0.40-0.41	22-38	0.33-0.39	5-12
	Avg	0.30	38	0.40	30	0.36	8
M48	Range	0.19-0.28	18-49	0.36	17	0.23-0.30	5-10
	Avg	0.24	34			0.26	8

This tabulation shows that the best towing performance considering all snow wetnesses was obtained with the girderized-track vehicles (D6, LGP-D7, and LGP-D8), followed by the weasel M29, the otter M76, and then the high-ground-pressure vehicles (M5A4, M4, and M48) which also have comparatively large bogies. The latter group of vehicles, however, showed a somewhat better performance in wet snow than the otter M76. In terms of slip performance, the general ranking of the vehicles is the same, but the high-ground-pressure vehicles were more efficient than the otter M76 in dry snow and attained the best over-all efficiency in wet snow. The reason for the low percentage of slip of the high-ground-pressure vehicles operating in wet snow is that these vehicles compact the wet snow to near ice conditions and the large rubber grousers do not penetrate the hard icy surface, causing the tracks to attain their maximum traction at comparatively low slip.

Effects of vehicle characteristics.

49. Importance of vehicle characteristics becomes apparent when the towing performances of vehicles in snow are observed. It becomes obvious that characteristics such as weight, contact pressure, distribution of weight, location of dynamic center of gravity (particularly for vehicles that are required to tow loads), and type of track system are important in the design of an over-the-snow vehicle. It was observed that track systems that distribute the load of a vehicle uniformly gave the best performance in snow. It can be said that the pontoon-type track is the best developed to date and that the girderized type of track is second best.

Use of Coulomb's equation to
estimate traction capacity.

50. In recent years, theoretical approaches have been made to define the drawbar pull performance of vehicles traveling in soils and snow by applying Coulomb's empirical equation ($S = c_e + \sigma_e \tan \phi_e$),* which expresses the shearing resistance (S) of a material in terms of the normal load (σ), the cohesion (c), and the apparent angle of internal friction (ϕ) of the material. The subscript "e" is usually referred to as "effective values." Some of the data obtained during the Greenland test program permitted a consideration of the elements given in the equation commonly used to express vehicle performance in terms of towing ability; therefore, some exploratory analyses were made, and measured and computed values were compared.

Vehicle-property measurements. The components of the tractive coefficient, maximum drawbar pull and vehicle weight, were plotted (Plate 53) for several areas where vehicles of different weights were tested in 1955. Similar plots were made for the 1957 tests (Plate 54), which were performed during short periods from May to July, in order that weather conditions would be varied, and in which a range of vehicle weights was tested. Although it is recognized that the traction capabilities of the vehicles tested were somewhat different, estimates for c and ϕ values could be obtained in this manner. The points on most of the plots fitted a straight line that passed through the origin. Since the maximum drawbar pull occurs with some track slippage, the results indicate that whenever the compacted snow underneath the track of a vehicle is put into motion by track slippage, the traction that a vehicle is capable of developing, and hence its trafficability, is entirely dependent on the dynamic frictional resistance of the snow. The equations for the lines drawn in Plates 53 and 54 are similar to Coulomb's equation for cohesionless materials.

The ϕ values determined from the data plots (Plates 53 and 54) indicate that the apparent angles of internal friction developed were in the order of 20° for wet snow, 25° for moist snow,

* D. W. Taylor, *Fundamentals of Soil Mechanics* (New York, N. Y., John Wiley and Sons, Inc., March 1950).

16 to 22° for dry snow, and 30° for dry age-hardened snow.

Comparison of measured and computed vehicle towing performance. The shear strengths computed from the data obtained with the 2-1/4-in. torque tube in 1955 and the variable-load shear vane in 1957 were plotted, and a straight line was used (see Plate 4 for examples of data plots) to define the relation between shear strength (plotted as ordinate) and normal stress (plotted as abscissa). The angle of internal friction was determined from the slope of the line, and cohesion was determined by the intercept of the line by the ordinate. The c and ϕ values determined in this manner were then substituted into the following modified Coulomb equation, and the computed towing performance of the weasel M29C was determined.

$$S = c_e + \sigma_e \tan \phi_e \tag{1}$$

where

S = shear strength in pounds per square inch
c = cohesion in pounds per square inch
σ = normal stress in pounds per square inch
ϕ = angle of internal friction
subscript e = effective values

Substituting $\frac{DP}{A}$ for S and $\frac{W}{A}$ for σ in Equation 1 gives

$$\frac{DP}{A} = c + \frac{W}{A} \tan \phi$$

where

DP = drawbar pull in pounds
W = vehicle weight in pounds
A = vehicle track area in square inches

Simplifying, $DP = cA + W \tan \phi$. Dividing by W and simplifying, $\frac{DP}{W} = \frac{cA}{W} + \tan \phi$. Since $\frac{DP}{W}$ = tractive coefficient (TC) and $\frac{A}{W} = \frac{1}{\sigma}$, the equation becomes

$$TC = \frac{c}{\sigma} + \tan \phi \tag{2}$$

For cohesionless materials, Equation 2 reduces to

$$TC = \tan \phi \tag{3}$$

Since the maximum drawbar pull occurs with track slippage, the residual readings obtained for the "moved position" with the 2-1/4-in. torque tube and variable-load shear vane were used to compute vehicle performance. The following tabulations compare measured and computed towing performances of the weasel M29C, using c and ϕ values obtained with the 2-1/4-in. torque tube and variable-load shear vane. The values shown in column 5 were computed using Equation 3, the values in column 7 were computed using Equation 2.

Residual Readings (Moved Position)

Item No. and Test Site	Grain Nature	c, psi	ϕ Degrees	ϕ tan ϕ	Tractive Coefficient Measured	Tractive Coefficient Computed
1	2	3	4	5	6	7
			2-1/4-in. Torque Tube Measurements			
			Wet Snow			
59B	Dd	0.8	32	0.62	0.36	1.10
60B	Dd	0.7	34	0.67	0.31	0.73
61B	Dd	0.0	53	1.33	0.33	1.33
62B	Dd	0.1	52	1.28	0.35	0.41
			Moist Snow			
63E	Dd	0.2	38	0.78	0.37	0.49
			Dry Snow			
64G	Db	0.5	28	0.53	0.40	0.70
67I	Db	0.7	20	0.36	0.36	0.78
69J	Fa	0.6	47	1.08	0.31	0.77
70J	Fa	1.7	29	0.55	0.26	1.27
			Variable-Load Shear Vane Measurements			
			Dry Snow			
172	Db	0.30	18.8	0.34	0.42	0.52
173	Db	0.24	13.4	0.24	0.42	0.38
174	Db	0.62	10.8	0.19	0.48	0.56
177	Db	0.24	27.4	0.52	0.43	0.76
			Moist Snow			
178	Db	0.12	29.2	0.56	0.51	0.63
179	Db	0.15	31.7	0.62	0.53	0.71
180	Db	0.12	24.7	0.46	0.39	0.53
181	Db	0.15	23.7	0.44	0.33	0.53

An examination of the last three columns in the preceding tabulation reveals that the computed tractive coefficients are generally much larger than the measured values. A comparison of computed and measured values was made by plotting the values given in column 6 against the values given in columns 5 and 7. These plots are shown in Plates 55 and 56. In Figures 1 and 2, c and ϕ were used to compute tractive coefficient (Equation 2), and in Figures 3 and 4, ϕ only was used (Equation 3). Figures 1, 2, and 3 of Plate 55 show that an inverse relation is apparent between computed tractive coefficients and those measured with the torque tube, and Figure 4 shows no relation. The best relations appear to be in Figures 1 and 2, in which cohesion was used to compute tractive coefficients. On the other hand, the plots for the variable-load shear vane (Plate 56) show a direct relation between computed and measured tractive coefficients, and the data are in reasonable agreement regardless of whether or not cohesion was used in computing the tractive coefficients. Consequently, it was concluded that the variable-load shear vane shows some promise as a means of measuring tractive coefficients, but that further work is required with this and similar instruments in order to determine whether or not more accurate results can be obtained.

Rolling resistance.

51. After most of the towing tests with self-propelled vehicles, the force required to pull these vehicles in neutral gear over virgin snow was measured, the results of these tests are given under the

heading "Towed Test Data" in Tables 13-16. These test results are considered only as estimates of rolling resistance because some vehicle drag or negative track slippage was apparent. Furthermore, while a vehicle is towing a load, its attitude is pitched downward at the rear (amount depending upon magnitude of towed load), and sinkage is greater because of track slippage; whereas when a vehicle is being towed forward, it is usually trimmed level, and track slip is negligible. The results are therefore not directly comparable.

During the course of the test programs, the towing force required to pull most of the vehicles tested over a level, dry, age-hardened snow area and over a highly compacted, moist snow area was determined. In both cases the areas were strong enough to support the vehicles so that only the grousers penetrated the snow. The force required to tow the vehicles was determined on both dry and moist compacted areas because in the latter case, and also on wet snow, water lubricates the track and the towing force required under these conditions is less than that required on dry, cold snow. The towing forces obtained in this manner were assumed to be the vehicle frictional resistances, and they are given below.

			Frictional Resistance			
			Dry Snow		Moist and Wet Snow	
Vehicle	Vehicle Weight, lb	Ground-Contact Pressure psi	Pull lb	Per Cent Vehicle Weight	Pull lb	Per Cent Vehicle Weight
Weasel M29C	5,450	1.68	610	11.2	500	9.2
Otter M76	9,960	1.72	1080	10.8	780	7.8
Standard D6 tractor	18,340	3.17	1840	10.0	1600	8.7
Hi-speed tractor M5A4	25,440	6.37	3200	12.6	2910	11.4
Hi-speed tractor M4	31,400	7.02	5000	15.6	3930	12.5

From the preceding tabulation it can be seen that for dry snow, frictional resistance ranged from about 10 to 15 per cent of the vehicle weight. It is to be noted that as ground-contact pressure and weight of vehicle increased, the frictional resistance (pull) increased. It is believed, however, that for conventional low-ground-pressure tractors, frictional resistance will increase as a function of ground-contact pressure rather than vehicle weight. For moist and wet snow, the relations are the same except the values are somewhat less.

As previously stated, the force required to tow a vehicle over a hard, compacted snow was identified as frictional resistance. The towing force required to pull a vehicle over virgin snow was termed "motion resistance." The difference between these readings (motion resistance minus frictional resistance) was considered an estimate of the rolling resistance encountered in virgin snow. The results of such a computation, using average values for each snow class determined from the data given in Tables 13-16, are given on the following page.

It can be seen that the lowest rolling resistances in terms of per cent vehicle weight were measured in dry snow and the highest in wet snow; rut depth also followed a similar pattern. Rolling resistance in terms of per cent of vehicle weight shows, in general, an increase with an increase in vehicle weight and ground-contact pressure for the dry and moist snow. For the wet snow, rolling resistance in terms of per cent vehicle weight remained fairly constant for all vehicles.

Vehicle	Snow Condition	Vehicle Weight, lb	Ground-Contact Pressure psi	Average Rolling Resistance Pull lb	Per Cent Vehicle Weight	Rut Depth in.
Weasel M29C	Dry	5,450	1.68	50	0.9	1.6
	Moist			200	3.7	3.5
	Wet			550	10.0	—
Otter M76	Dry	9,960	1.72	860	8.6	3.5
	Moist			580	5.8	5.0
	Wet			1090	10.9	3.7
Standard D6 tractor	Dry	18,340	3.17	1150	6.2	3.8
	Moist			2100	11.4	11.5
	Wet			—	—	—
Hi-speed tractor M5A4	Dry	25,440	6.37	1840	7.2	6.2
	Moist			—	—	—
	Wet			2640	10.4	28.2
Hi-speed tractor M4	Dry	31,400	7.02	2140	6.8	8.0
	Moist			3070	9.8	13.5
	Wet			3220	10.3	—

XX. TOWED TESTS

52. Towed tests were conducted with 10-ton-capacity Otaco sleds and a 6-ton-capacity Athey wagon. The objectives of these tests were to compare the pull required to tow these vehicles over various snow conditions, and to determine relations between first-pass towing force and snow-property measurements. The forces required to start and keep a towed vehicle moving are expressed as coefficients obtained by dividing the towing force by the gross vehicle test weight. All tests were conducted with the vehicles traveling a straight-line path at approximately 2 mph. The test data are summarized in Tables 18 and 19.

Sled tests.

53. *Description of sleds.* The sleds were equipped with 24-in.-wide and 100-in.-long steel or plastic-coated steel runners, and it was planned to test them with 5-, 10-, and 15-ton payloads. In 1955, only sleds with steel runners were tested. The material used for ballast (419-lb fuel drums) in these tests was too bulky to obtain payloads in excess of 5 tons; however, in a few tests the otter was used as a 10-ton payload. In 1957, concrete beams were used for ballast, and this permitted testing the sleds at 5-, 10-, and 15-ton payloads. The 1957 tests included sleds with steel runners and also sleds with steel runners coated with 1/16-in.-thick Kel-F and Teflon plastic materials. These coatings consisted of sheet material cemented to the runners by a special vacuum and heat process and an angle-iron trim placed around the edges of the runners. Three test sleds were each loaded to one of the three payloads, and comparative tests were made by shifting the three types of runners from one sled to the other until each runner had been tested at each load.

Types of tests. Prior to testing, it was thought that the resistance to the runners sliding on snow compacted by a tractor would be less than that on the softer virgin snow, and that compacted snow test results would be more difficult to correlate with snow-property measurements than virgin snow test results; therefore, tests were conducted with the sled hitched close behind the tractor so that the sled's runners traveled on snow compacted by the tractor towing it (referred to as compacted snow tests), and also with the sled hitched to the tractor by means of a 100-ft-long cable, so that the sled runners traveled over virgin snow (referred to as virgin snow tests). A compacted snow test was run first, followed immediately by a virgin snow test.

A total of 133 sled tests are reported herein; 14 were run in 1955 and 119 in 1957. In the 1955 program, five tests were run at the 5-ton payload, and two at the 10-ton payload, in each of the two snow conditions; then two tests were made in the compacted snow with two sleds, loaded to the 5- and 10-ton payloads, respectively, hitched in tandem. In the 1957 program, about seven tests were conducted with each of the steel, Kel-F, and Teflon runners, at each of the 5-, 10-, and 15-ton payloads, in each of the two snow conditions. Data from the 1955 and 1957 tests are shown in Tables 18 and 19, respectively. In Table 19, the data for the compacted snow tests followed by that for the virgin snow tests are listed in the order of increasing test weight. Data for the steel runner tests are given first, followed successively by the data for the Kel-F runners and the Teflon runners. The majority of data shown in Table 19 for static friction were obtained after the sled was "parked" for 1 min, or after 1-min "freeze-down" time.

Correlation of kinetic and static friction with snow-property measurements. Preliminary analyses were made of the correlation of kinetic and static friction with the following snow-property measurements: cone index, compaction in remolding cylinder, rating cone index, initial vane shear, residual vane shear, Ramm hardness number, Canadian hardness, 2-1/4-in. torque tube initial shear, 2-1/4-in. torque tube residual shear, drop-cone hardness, density, and snow temperature. Before-traffic and one-pass measurements of these snow properties were plotted against kinetic and static friction. The before-traffic data plotted against static friction and the one-pass data plotted against both kinetic and static friction were widely scattered, and no definite conclusions could be made. Therefore, the discussion that follows includes only a consideration of the kinetic friction effects measured for the sled equipped with steel runners, loaded to a 5-ton payload, and operating on dry snow. Relatively more data are available from these tests, and the range in kinetic friction is greatest for the sleds with steel runners.

Examples of several data plots (cone index, initial vane shear, density, and snow temperature vs coefficient of kinetic friction) for the 5-ton-payload, steel runner tests on compacted and virgin snow are given in Plates 57 and 58, respectively. The plots show that kinetic friction varied little for a comparatively wide range in snow-property measurements, and that kinetic friction decreased with an increase in snow strength and increased with an increase in snow temperature. The lines drawn on the compacted and virgin snow plots are somewhat parallel, with the virgin snow producing the higher kinetic friction coefficient value (approximately 0.028 increase) for the same snow property measurement. The increase in kinetic friction for virgin snow may be attributed to the increase in frontal resistance of the lead runners in breaking away the undisturbed snow; sinkage was also greater in the virgin snow test runs. It is to be noted that item 258 in Plate 58 plots as an outlier. During this test and several others, snow froze to the bottom of the steel runner on the shady side of the sled and built up until the runners were higher than the snow surface (Fig. 20), necessitating much greater pull than normally required.

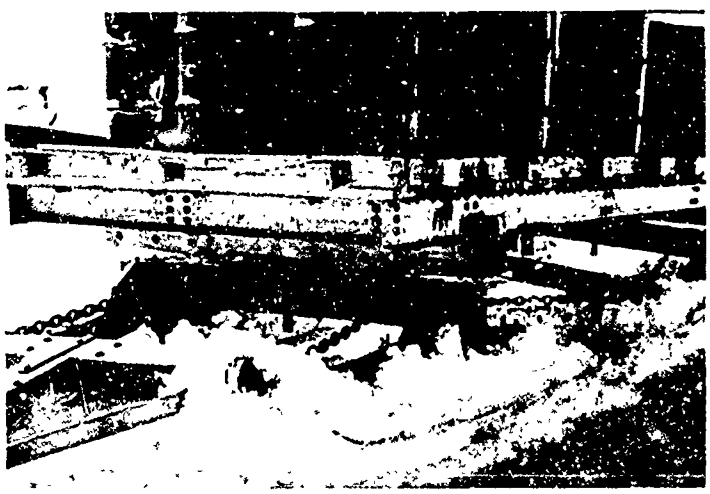


Figure 20. Snow frozen to runner.

Effects of snow-wetness class on kinetic and static friction. The kinetic and static friction data given in Tables 18 and 19 for the compacted and virgin snow tests were averaged for each type of runner, snow class, and payload. the results are tabulated below.

Payload tons	Snow Condition	Steel Runners Dry	Steel Runners Moist	Steel Runners Wet	Kel-F Runners Dry	Kel-F Runners Moist	Kel-F Runners Wet	Teflon Runners Dry	Teflon Runners Moist	Teflon Runners Wet
				Coefficients of Kinetic Friction						
5	Compacted	0.12	0.09	0.13	0.11	0.06	0.06	0.06	0.05	0.05
	Virgin	0.15	0.18	0.14	0.11	0.08	0.10	0.06	0.06	0.10
10	Compacted	0.12	0.12	0.08	0.12	0.08	0.05	0.07	0.06	0.05
	Virgin	0.15	0.17	0.16	0.12	0.10	-	0.06	0.08	0.10
15	Compacted	0.12	0.07*	0.08	0.10	—	0.07	0.07	0.05*	0.05
	Virgin	0.15	0.13*	0.15	0.10	—	0.12	0.09	0.07*	0.11
				Coefficients of Static Friction						
5	Compacted	[illegible]	0.34	0.42	0.27	0.13	0.21	0.17	0.20	0.17
	Virgin	0.17	0.48	[illegible]	0.11	0.08	0.10	0.06	0.06	0.10
10	Compacted	[illegible]	0.17	[illegible]	0.28	[illegible]	0.17	0.20	0.14	0.19
	Virgin	0.44	0.45	[illegible]*	0.21	0.20	0.20	0.16	0.17	0.24
15	Compacted	[illegible]	0.17*	[illegible]	0.25	—	0.17	0.18	0.13*	0.17
	Virgin	0.31	0.45*	[illegible]	0.22	—	0.26	0.18	0.16*	0.27

* One test only

Plots of snow wetness versus kinetic and static friction for the various payloads were made from the data given above, and are shown in Plates 59 and 60. From Plate 59 it can be seen that for all payloads and runner types, except the 10-ton-payload test on steel runners and the 15-ton-payload tests, the coefficient of kinetic friction for the compacted snow decreased until the snow became moist, after which little or no change occurred as the snow became wet. The change in the shape of the curve for the 10-ton-payload steel runners was caused by a high value obtained in a test (see item 278, Table 19) in which 1 in. of moist snow was underlain by dry, cold snow which caused the moist snow to stick to the bottoms of the steel runners. For the 15-ton-payload wet snow tests, the tractor and the runners rutted deep enough that the cross members of the sled (which have approximately 6 in. clearance) dragged a significant amount of heavy wet snow, thus resulting in higher drawbar pull and hence higher coefficients of kinetic friction than would normally be anticipated for wet snow. The plots also reveal that the coefficient of kinetic friction for Teflon-coated runners operating on dry snow is approximately half that of steel runners, and that the curves for the Kel-F plastic-coated runners fall about halfway between the steel and Teflon-coated runner curves. From an operational standpoint, this would indicate that a sled swing mounted with Teflon runners would require about half the number of tractors to tow it as compared with the number required to tow a similar sled swing mounted with steel runners. Snow wetness also appears to have little or no effect upon kinetic friction for Teflon-coated runners. The curves drawn for the virgin snow are different from the compacted snow curves in that the curves are somewhat higher, particularly for steel runners, than the compacted snow curves.

As can be seen from the plots of snow wetness versus coefficient of static friction in Plate 60, some inconsistencies were found and are indicated by the shapes of the curves drawn. In general, static friction for the compacted and virgin snow runs increased as snow wetness increased for steel runners, and decreased as snow wetness increased for the plastic-coated runners, with moist snow giving the lower values. Apparently, the heavy wet snow that piles up in front of

the sled as a result of deep ruts makes it necessary that a greater towing force be exerted to start the sled moving after 1-min "freeze-down" than that force required in cold, dry snow where rutting is usually less, but adhesion between the snow and runner greater. This, however, is contrary to what normally would be expected.

The static friction for the Teflon coated runners appears to be half that for the steel runners for all snow wetnesses and payloads. The Kel-F curves fall between the steel and Teflon curves for dry snow, but closely approach the Teflon curve for moist and wet snow.

Comparison of kinetic and static friction. Plate 61 shows a comparison of some of the traces obtained with a 10-ton-capacity Otaco sled, loaded with a 5-ton payload and mounted with steel runners, operating in wet and dry, compacted and virgin snow. It is to be noted that the static pull was quite erratic and an assortment of patterns was obtained, the runs made on virgin snow, however, gave smoother traces than those on compacted snow. Once the sled started moving, it can be seen that the magnitude of the kinetic pull oscillated at a high frequency over a fairly wide range. This oscillation of drawbar pull was caused by the large clearance between the tractor drawbar pin and the sled tongue eye.

From the data given in the table on page 51, it can be seen that for the steel runners, regardless of payload or snow wetness, static friction is three to five times greater than kinetic friction, and for Kel-F and Teflon runners, it is two to three times greater.

Effects of contact pressure on kinetic friction. The tests conducted with the 5-, 10-, and 15-ton payloads represent contact pressures of 2.5, 3.6, and 5.0 psi, respectively. This range of contact pressures showed no effect upon kinetic friction of the sleds towed at speeds of approximately 2 mph.

Effect of sled arrangement, in a string, on kinetic friction. During the 1955 test program, two sled tests were conducted at mile 220 (items 94 and 95, Table 18) to determine the effects of the arrangement of sleds with different payloads on kinetic friction. In the first test (item 94) a sled loaded with a 5-ton payload (sled A), followed by a sled loaded with a 10-ton payload (sled B), were hitched in tandem behind a tractor. In the second test (item 95) the sled order was reversed. In both tests the pull on each sled was measured by recording dynamometers. The results of these tests are given below.

Sled A, 5-ton Payload				Sled B, 10-ton Payload				Both Sleds			
Pull, lb		Coefficient of Friction		Pull, lb		Coefficient of Friction		Pull, lb		Coefficient of Friction	
S*	K**	S	K	S	K	S	K	S	K	S	K
Item 94 (Tractor, Sled A, and Sled B)											
4100	2600	0.21	0.15	5700	2700	0.20	0.10	9800	5300	0.21	0.11
Item 95 (Tractor, Sled B, and Sled A)											
[illegible]	1800	0.16	0.06	4300	3500	0.25	0.18	9500	5300	0.20	0.11

* Static friction
** Kinetic friction

It can be noted that the total kinetic forces required for both sled combinations are the same, however, the forces measured for each individual sled do vary according to the arrangement of sleds. When a [illegible] placed in the lead position, the static and kinetic friction was greater than when it was placed in the second position.

Durability of plastic materials on runners. During the period of testing and during a round trip to Fist Clench, the plastic-coated steel runners were used for about 550 miles, and showed no appreciable wear. An examination of the plastic coatings used indicated that Kel-F is roughly four times harder than Teflon. The Teflon runners had several noticeable small scratches, whereas only hairline scratches were evident on the Kel-F runners. Several small blisters were also evident on the Teflon runners; however, they were too small to affect the runner performance. Nevertheless, with time, these blisters might increase in size and then break, which might result in poor runner performance.

In order to protect the outer edges of the plastic coatings, a 1/2- by 3/4-in. angle iron, 1/8 in. thick, was placed along the edge of the runners. The edging was fastened to the runners by 3/16-in. countersunk flathead studs spaced about 10 in. apart. This method proved to be very unsatisfactory in turning because sufficient shear stress was developed to shear the screws on the back one-third of the runner. In order to be able to adapt a proper edging, a change should be made in the basic design of the runner by moving inward all the topside bracing so as to permit fastening the edging firmly to the runner. Also, it would be desirable to have the plastic molded near the edge so that the metal trim can be seated even with the wearing surface of the plastic material, thus minimizing the side stress imparted to the edging in turning.

Tracked trailer tests.

54. During the 1957 test program, several towed tests were conducted with a tracked Athey wagon carrying a 6-ton payload. Two tests were run on dry snow and one each on moist and wet snow. The tests with this vehicle were limited because of its high-ground-contact pressure (17.6 psi) and because its high center of gravity caused this vehicle to tilt and lose its load easily, particularly if the trailer passed over a deep rut or test pit that was filled with new snow. The test data collected in these tests are summarized in Table 19 as items 351-354.

The test data in Table 19 show that the Athey wagon required a drawbar pull of 16 to 24 per cent of its weight to keep it moving in dry snow and 21 and 23 per cent in moist and wet snow, respectively. For similar snow conditions, the sleds mounted with steel runners required a towing force of about 12 per cent for dry snow, and about 7 to 9 per cent for moist and wet snow, respectively. On a comparative basis, the sleds required 4 per cent less pull than the tracked trailer in dry snow, and about 33 per cent less pull in moist and wet snow. The ground-contact pressures at which the sleds were tested ranged from 2.5 to 5.0 psi, however, the ground-contact pressure at which the Athey wagon was tested was 17.6 psi. It is believed that proper design of an Athey wagon-type tracked trailer, using lower ground-contact pressures, would produce a trailer that could at least equal sled performance.

XXI. CORRELATION OF SNOW-PROPERTY MEASUREMENTS

55. The various other snow-property measurements made were each compared with cone index to determine the relation between the various properties and snow strength as indicated by cone index. Cone index was selected for the correlation study because cone index data were available for all tests and also because cone index gave one of the best correlations for the various vehicle-performance relations established. Plots were made for the before-traffic data since all the snow properties were measured before traffic, whereas all were not always measured after traffic was applied. Each point shown in the data plots in Plates 63-73 represents the average data for a test lane, while Plate 62 shows a comparison of individual cone index and initial vane shear measurements taken at the same depth and location for one test. Symbols are used in Plates 63-73 to distinguish between the different snow types. Whenever profile measurements were made, the average of the data collected in the critical layer was used in the data plots; however, when a snow-property measurement was made without regard to depth, such as drop-cone hardness and torque tube readings, the average of the 0- to 6-in.-depth cone index was used in the data plots. In determining the amount of compaction and the rating cone index, the same length sample was used but the compaction effort was varied according to the

weight class of the vehicles tested or type of test run. In the data plots the curves represent visual averages; if a separation could be made on the basis of snow type, individual curves were drawn. Whenever a linear relation was apparent, the position of the line and the quality of the relation were determined by statistical methods. Also, where linear relations were apparent between cone index and other snow-property measurements, it was assumed that the relations between the other snow measurements were also linear and the statistical analysis was extended to correlation between other snow-property measurements. If the plotted data were widely scattered and no relation was apparent, the plots are shown without curves.

Cone index versus profile strength measurements.

56. The relations determined for the profile strength measurements (compaction, rating cone index, vane shear, Ramm hardness number, Canadian hardness, and drop-cone hardness) and cone index show that the relation between cone index and vane shear, Ramm hardness number, Canadian hardness, and drop-cone hardness are, in general, straight lines throughout the data range regardless of snow type. These data plots are shown in Plates 62, 66, 67, 68, 69, and 71. A comparison of Plates 62 and 66 reveals that greater variation between data can be expected whenever single measurements are compared than when average data are used for correlation purposes. Some of the variation in the Ramm and Canadian hardness correlations (Plates 68 and 69) can be attributed to the same cause since only 1 to 3 sets of these readings were used in determining averages for a given test, whereas 10 to 20 sets of readings were used in obtaining average cone index. Other variations in the data plots may have resulted from (a) actual snow variations, (b) inaccuracies in the reading of the instruments, and (c) different depths at which measurements were made. For example, the range in the torque wrench used with the shear vane was 600 in.-lb and the wrench was graduated in 20-in.-lb increments, making it difficult to obtain accurate torque readings in the low strength range where most of the residual vane readings occurred. In determining the strength of a layer of snow (for example, the 0- to 6-in. depth), the 0-, 3-, and 6-in. readings were averaged to determine cone index; the vane shear strength was an average of the 2- to 6-in. depth for some of the readings and the 0- to 6-in. depth for others; and the Ramm hardness readings involved the entire depth considered. High or low surface readings, therefore, would account for some of the variation in cone index-initial vane shear relation, and intermediate hard layers between 0- to 3-in. and 3- to 6-in. depths would affect cone index-Ramm hardness number relations.

The correlation coefficients determined for the profile strength measurements and cone index where linear relations were apparent are given in the tabulation below. All the correlations were significant at the 1 per cent level.

Snow Property	Degrees of Freedom, n − 2	Correlation Coefficient, r
Initial vane shear (individual measurements)	38	0.760
Initial vane shear	263	0.795
Residual vane shear	263	0.665
Ramm hardness	166	0.863
Canadian hardness	164	0.660
Drop-cone hardness	70	0.523

Plates 63 and 64 show data plots for cone index and compaction that occurred in the remolding cylinder after 25 and 50 blows, respectively, of a 3-lb drop hammer dropped 12 in. The data plotted in Plate 63 are data collected during tests of the lightweight vehicles; these data consist of average 0- to 6-in. cone index for a test lane and the cylinder compaction that occurred after 25 blows. The data shown in Plate 64 were collected during tests of the vehicles weighing more than 10,000 lb; cone indexes were averaged for the 0- to 12-in. depth for each test and the compaction effort applied for 50

blows. An examination of these curves reveals that the relations are reasonably well defined and that one curve can be used for all snow types. It is also to be noted that the 25-blow curve plots to the left of the 50-blow curve, and the left side of the 25-blow curve is much steeper than that of the 50-blow curve. This difference can be attributed to the fact that the average cone index for the 0- to 6-in. layer is usually less than the average for the 0- to 12-in. depth and also to the fact that the greatest amount of compaction occurs with the first 25 blows (see Fig. 3 of Plate 31).

The relations derived for cone index and rating cone index after 25 and 50 blows are shown in Plate 65. For these data plots, the best relations were obtained by drawing separate curves on the basis of snow wetness. There are, however, two exceptions in that the moist snow data in the upper plot are too scattered to permit drawing of a curve, and the wet fine-grained snow data collected in 1954, shown in lower plot, plot in an area between the dry fine-grained snow and the wet coarse-grained snow. An examination of the individual data plotted in the lower plot reveals that the top 5 in. of these samples was dry, hard, fine-grained snow which has apparently influenced the characteristics of these samples. The curves drawn for dry snow are similar for both compaction efforts; however, the 25-blow wet snow curve continues to rise slightly at the high cone index range, whereas the 50-blow wet snow curve peaks at about 15 cone index and then drops rather sharply. The moist snow 50-blow curves show a sharp increase in rating cone index throughout the range of cone index shown. It is also to be noted that in the dry, hard, fine-grained snow (data from 1954 tests, shown as dots in Plate 65), the rating cone index, in most instances, is less than the before-traffic cone index.

Cone index versus 2-1/4-in. torque tube shear strength measurements.

57. Data plots for cone index and 2-1/4-in. torque tube initial and residual shear strength measurements are shown in Plate 70. It can be seen that the data are widely scattered, and that the curves drawn indicate that the shear strength increases with cone index until a certain maximum shear strength value is reached, then decreases with further increase in cone index. Some of the variation in these data comparisons can be attributed to the variation in penetration of the torque tube under different loads and in various snow types, whereas the cone index measurements represent the 0- to 6-in. depth only. In dry hard snow, little sinkage of the torque tube occurs regardless of load; but in dry soft snow, the 1-psi load will sink the tube several inches, whereas the 5-psi load may sink the instrument to a depth of 12 in. or more. A depth-by-depth comparison of cone index and torque tube shear strength might yield a better relation.

Cone index versus density.

58. An analysis of plots of cone index versus density, shown in Plate 72, shows that for the dry fine-grained snow a fairly good relation is apparent for the cone index range of 0 to 20, which represents the dry, hard, fine-grained snow. Beyond this range, the data become more widely scattered and a wide range of cone index represents a small range in density change. Little or no relation is apparent for the moist and wet snow tested. It can be seen that the moist and wet snow represent a wide range of cone index, but density ranged only from about 0.40 to 0.50 g per cm^3. Fine-grained wet snow was not subjected to frequent cold spells, and this resulted in a wetter and softer snowpack. On the other hand, the coarse-grained snowpacks were subjected to frequent cold spells, and consequently higher cone index readings were obtained in the partially frozen layers and somewhat drier snowpacks.

Cone index versus snow temperature.

59. The cone index-snow temperature data plot is shown in Plate 73. These data are widely scattered and no relation is apparent.

Statistical analysis of snow-property measurements.

60. In the analysis of cone index versus initial vane shear, residual vane shear, Ramm hardness, Canadian hardness, and drop-cone hardness, linear relations were apparent. It was therefore assumed that the relations between these snow-property measurements were also linear, and the statistical analysis was extended to consider these linear relations. Since the correlation coefficient will not change if the independent and dependent variables are interchanged, an average of the correlation coefficients was determined for each comparison. A summary of the analysis is given in the following tabulation. The tabulation shows that the average correlation coefficient was highest for cone index, followed by Ramm hardness number, and then initial vane shear strength.

Dependent Variable $\hat{Y}$	Independent Variable X	Degrees of Freedom, n-2	Linear Regression Equation	Correlation Coefficient r*	Standard Error of Estimate, Sy.x
Initial vane shear strength	Cone index	263	$\hat{Y} = 0.085X + 0.701$	0.795	0.665
Residual vane shear strength		263	$\hat{Y} = 0.009X + 0.031$	0.665	0.102
Ramm hardness number		166	$\hat{Y} = 0.774X + 0.296$	0.863	5.66
Canadian hardness number		166	$\hat{Y} = 67.68X + 9.80$	0.660	1120.3
Drop-cone hardness number		70	$\hat{Y} = 1.763X + 15.36$	0.523	49.13
Average				0.701	
Cone index	Initial vane shear strength		——	0.795	——
Residual vane shear strength		263	$\hat{Y} = 0.079X$	0.646	0.103
Ramm hardness number		149	$\hat{Y} = 7.83X - 1.72$	0.827	6.42
Canadian hardness number		148	$\hat{Y} = 592.2X - 19.42$	0.491	1280.2
Drop-cone hardness number		69	$\hat{Y} = 18.28X - 11.50$	0.524	46.29
Average				0.657	
Cone index	Residual vane shear strength		——	0.665	——
Initial vane shear strength		263	——	0.646	——
Ramm hardness number		149	$\hat{Y} = 39.52X + 5.70$	0.586	9.25
Canadian hardness number		146	$\hat{Y} = 2855.1X + 563.4$	0.332	1385.7
Drop-cone hardness number		70	$\hat{Y} = 80.65X + 31.94$	0.316	54.70
Average				0.509	
Cone index	Ramm hardness number		——	0.863	——
Initial vane shear strength		149	——	0.827	——
Residual vane shear strength		149	——	0.586	——
Canadian hardness number		163	$\hat{Y} = 76.45X + 98.64$	0.612	1116.2
Drop-cone hardness number		70	$\hat{Y} = 1.85X + 20.11$	0.476	50.69
Average				0.673	
Cone index	Canadian hardness number		——	0.660	——
Initial vane shear strength		148	——	0.491	——
Residual vane shear strength		146	——	0.332	——
Ramm hardness number		163	——	0.612	——
Drop-cone hardness number		70	$\hat{Y} = 0.022X + 15.9$[illegible]	0.620	45.21
Average				0.543	
Cone index	Drop-cone hardness number		——	0.523	——
Initial vane shear strength		69	——	0.524	——
Residual vane shear strength		70	——	0.316	——
Ramm hardness number		70	——	0.476	——
Canadian hardness number		70	——	0.620	——
Average				0.490	

* All correlation coefficients (r) are significant at the 1 per cent level.

PART V. EVALUATION OF INSTRUMENTS, VEHICLE STRUCTURAL FEATURES, AND PERFORMANCE OF MEDIUM TANK M48

XXII. INSTRUMENTS

61. The instruments used to obtain the various snow-property measurements have been evaluated on the basis of accuracy and conformity to the military requirements of simplicity, light weight, portability, speed of reading, etc. Accuracy is expressed as the weighted average of the per cent error determinations made for each type of vehicle test, and conformity to military specifications is based on experience in field usage of the instruments. The results of this analysis are described in the following paragraphs.

Accuracy.

62. A comparison of the accuracy of the snow-property measurements made for all snow types and vehicle tests, expressed in terms of per cent error, are tabulated below.

	Before-Traffic Data				
	Self-Propelled Tests		Towing Tests		
Snow Property	No. of Tests	Per Cent Error	No. of Tests	Per Cent Error	Weighted Average Per Cent Error
Cone index	124	13.2	76	7.4	11.0
Compaction in remolding cylinder	87	23.0	43	8.6	18.2
Rating cone index	88	45.1	43	16.4	35.7
Initial vane shear	110	18.5	54	12.9	16.7
Residual vane shear	110	28.5	—	—	28.5
Ramm hardness	78	22.5	46	11.3	18.3
Canadian hardness	77	26.0	45	14.5	21.8
2-1/4-in. torque tube initial shear	33	19.6	16	11.4	16.9
2-1/4-in. torque tube residual shear	33	15.5	17	11.0	14.0
Drop-cone hardness	32	12.4	15	11.8	12.2
Density	83	26.7	72	11.4	19.6

From an examination of the "Weighted Average Per Cent Error" column it can be seen that two snow-property measurements (cone index and drop-cone hardness) show relatively small per cent errors and two (rating cone index and residual vane shear) show high per cent errors in regard to correlation with vehicle performance. The others are grouped close together in regard to per cent errors.

Adaptability to military field use.

63. In the following paragraphs the instruments used in this study are evaluated on the basis of their simplicity, weight, durability, and speed of reading. In all cases, speed of reading includes an estimate of the time involved in taking one set of readings and performing the necessary tabulations required to put the data into usable form for interpreting vehicle performance. The analysis takes into consideration the fact that an instrument man and recorder were used in obtaining the data for all snow-property measurements.

Cone penetrometer. The cone penetrometer is a lightweight, compact, and durable instrument.

The standard cone penetrometer weighs 3.5 lb; however, by using lighter metals and reducing the size of the instrument, a modified cone penetrometer has been developed that weighs 1.6 lb. When assembled, this instrument consists of only one part, which is a desirable feature for field use. The proving ring design feature of the cone penetrometer also gives this instrument a high degree of accuracy. The cone penetrometer was used during the entire period of the test program, and no mechanical difficulties were encountered. In obtaining a set of cone index data, readings were made at the surface and at vertical increments of 3 in. to a depth of 1 ft. A set of readings was obtained and the data averaged in about 2 min.

Remolding equipment. The remolding equipment was used to obtain rating cone index and snow compaction data. The cone penetrometer, discussed in the preceding paragraph, is also a part of this equipment when rating cone index measurements are made. For snow compaction data only, a cylinder, drop hammer, and a tape are used. The weight of these three pieces of equipment is moderate (about 7 lb); the equipment is durable, but rather bulky. A shovel is also required with this equipment to dig around the undisturbed snow sample obtained by forcing the cylinder into the snow. Compaction data can be obtained in about 6 min, but about 12 min are required for a set of rating cone index data.

Shear vane. This instrument is also lightweight (about 3 lb), compact, and fairly durable. The shear vane was used during the entire test program, and the mechanical performance of the vane and torqu wrench was satisfactory except that, in shearing snow profiles containing thin ice lenses, the high torques applied caused the vanes to bend. A 600-in.-lb torque wrench, graduated in 20-in.-lb increments, was generally used. The use of a more sensitive torque wrench in soft snow would improve the accuracy of readings in such snow. A set of readings consists of readings made in the 0- to 6-in. and 6- to 12-in. layers. One set of readings can be obtained and tabulated in about 4 min.

Rammsonde penetrometer. This instrument is very durable, compact, and fairly light. For trafficability purposes one staff and one kilogram weight are adequate, making the total weight of the equipment approximately 5 lb. Penetration readings are made at 5-cm intervals. The instrument is easy to use and the time consumed in obtaining the data for one penetration is in the order of a few minutes; but the complex formulae used to determine a Ramm hardness number are too difficult for field use, and hence, the computations add several minutes to the obtaining of usable data.

Canadian hardness gages. These gages are light (about 2 lb), durable, and very compact. The measurements are made in a vertical wall of a pit, which means a shovel is required for excavation of the pit. A sufficient number of readings are made in each layer to determine a representative value for the layer. No mechanical difficulties were encountered during the test period. Including pit excavation and data tabulations, a set of usable data can be obtained in about 10 min.

2-1/4-in. torque tube. This equipment consists of a torque tube, torque wrenches, and sufficient lead weights to load the torque tube from 1 to 5 psi. The number of accessories required with this instrument, although fairly compact, make it rather heavy (about 25 lb) and cumbersome. Furthermore, a careless release of a lead weight to the bottom of the tube may completely destroy the vanes set at right angles inside the bottom of the tube. This occurred with the 5-in.-diameter torque tube. Otherwise, this instrument is fairly durable. To take a set of data with this equipment is time-consuming because four sets of independent readings are required at different unit loads. Before the data can be reduced to a usable form, shear strengths must be computed for each unit load, plots made of shear strength versus unit load, and then the shear strength read from the graph for the ground-contact pressure of the vehicles under consideration. It is estimated that about 20 min are required to obtain the necessary data and make the computations.

Drop cone. Like the torque tube, the drop-cone penetrometer consists of several parts, and

requires various-size weights that are used to load the cone to insure sufficient penetration (about 12 cm). The equipment is rather compact and lightweight (about 6 lb). Data collection with this instrument is time-consuming. Great care must be taken to insure that the bar which holds the drop cone is in a level position before release of the cone; also, when wind is blowing, the instrument may not drop in a normal position, thus necessitating another reading. In addition, the formula that is used to compute a hardness index is rather complex and difficult for field use. It is estimated that 15 min are required to obtain one set of data in usable form.

Density and snow-temperature measuring equipment. These measurements were made with the equipment provided in SIPRE's snow classification kit. In its present form this equipment, including a shovel, weighs about 10 lb and is cumbersome. Because it requires the taking of horizontal measurements in a vertical face of a pit, its use is time-consuming. For trafficability purposes, it is believed that the equipment can be redesigned to permit vertical sampling to the desired depth, thus eliminating the necessity for digging a pit except perhaps in snow profiles that contain ice lenses. A spring weighing system should also be substituted for the present triple beam balance. In addition to the time consumed in collecting data, tabulation of a weighted average from horizontal measurements is also time-consuming. It is estimated that the time required to obtain one set of density data is in the order of 25 min; about 10 min are required for an independent set of snow-temperature measurements.

Summary evaluation.

64. On the basis of accuracy and adaptability to field use, it is suggested that the cone penetrometer be accepted as the most practical instrument presently available. Furthermore, the acceptance of the cone penetrometer will permit soil and snow surfaces to be evaluated in terms of the same unit of measure, which is highly desirable from the military standpoint. Because most snow types compact and then shear abruptly when being tested by a strength-indicating instrument, work should be continued in an attempt to develop a drop-type cone penetrometer that will penetrate the snowpack about 18 in., as well as shear vanes that can be used to determine the shear strength of the surface layer of compacted snow and provide comparable instrument and vehicle c and ϕ values. The data obtained with the latter type instruments could be used in theoretical studies.

XXIII. NOTES AND OBSERVATIONS ON VEHICLE STRUCTURAL FEATURES

65. One of the principal problems that confronts movement of material and men over the ice cap is the slow speed of travel. Except in very soft snows, lightweight vehicles are capable of traveling 8 to 10 mph when loaded to their rated cargo capacity; however, if these vehicles are required to tow a load, the vehicle speed is reduced by approximately half. Vehicles weighing more than 10,000 lb include the low-ground-pressure prime movers, they are so geared that when towing a load in first gear, the tractor can travel approximately 1 mph, and in fifth gear, the maximum speed is about 5 mph. Without a tow load these tractors can travel at slightly higher speeds, but a ridged and swaled trail usually will not permit speeds in excess of 5 mph.

Much thought has been given to the design of a tracked prime mover that will give a towing speed of 8 to 10 mph. Hi-speed tractors with a reasonable tow load are capable of such speeds in some snow conditions. However, during the Greenland tests, it was noted that these vehicles, when traveling approximately 10 mph, deleteriously affected the surface of an established trail by producing deep ruts as a result of high ground pressure or braking action. Since tracked vehicles are steered by braking one track, the excess power during a braking action is transmitted to the opposite track, producing a high rate of slip because of the lack of traction. The result of intermittent braking action

is the development of a ridged and swaled trail, which makes travel difficult for following vehicles. Several such vehicles traveling over a trail will make the trail so rough that subsequent traffic must reduce its speed to a few miles per hour. The employment of present-day hi-speed-tractor-type tracks (but using smaller and more track bogies) and suspension systems with a ground-contact pressure reduced to less than 4 psi, and an all-powered-track, articulated* vehicle should give an increase in speed as well as all-around better vehicle performance. The articulation of vehicles permits easier turning, less trail deterioration, smoother riding, and an increase in traction since the second unit travels on snow compacted by the lead unit. All-wheel-drive wheeled vehicles with large-diameter low-pressure tires equipped with suitable chainlike traction devices should also give acceptable over-the-snow performance. Since most snow conditions offer sufficient bearing capacity and are deficient in traction capacity, it is suggested that, for increase in speed of ice-cap travel, the application of air-thrust type power be investigated. In the meantime, methods of improving track systems to increase traction should also be investigated.

XXIV. PERFORMANCE OF MEDIUM TANK M48 ON TRIP TO FIST CLENCH

66. Following the completion of the 1957 scheduled test program, an operational test run was made with the medium tank M48 from mile 30 to Fist Clench (mile 220) to determine if the tank was capable of negotiating the snow conditions encountered some 200 miles out on the ice cap. The following paragraphs present the performance data collected and discuss the problems encountered.

Performance tests and results.

67. En route, the performance tests made with the tank included (a) speed runs in a straight-line path, (b) tight turns with the vehicle going forward and backward, respectively, and (c) determination of the amount of turn the vehicle could make in neutral steer. Comparative tests were made on the hard compacted trail snow and on the virgin snow adjacent to the trail. All tests were conducted under full throttle. Data collected at several test areas are tabulated below.

Performance Data

Mile	Snow Condition	Trail Speed mph	Trail Rut Depth in.	Virgin Snow Speed mph	Virgin Snow Rut Depth in.	Neutral-Steer Turning degrees Trail	Neutral-Steer Turning degrees Virgin Snow	Virgin Snow Turning Radius, ft Forward	Virgin Snow Turning Radius, ft Reverse
30	Wet, soft	4-6	10.0	3	20.0	30	15	40	46
78	Dry, medium hard	12-15	4.0	6-8	9.0	150-180	40	—	16
135	Dry, medium hard to soft	9	5.5	6-7	13.0	—	30	33	36
220	Dry, medium hard	10	4.5	5	10.5	380	40	23	20

From the tabulation it can be seen that the medium tank M48 encountered no difficulties in negotiating the snow conditions on the trip to Fist Clench, and actually performed better than anticipated. The medium tank M48 could travel about 4 to 8 mph in both wet and dry, soft snow and 9 to 15 mph in medium hard, dry snow, between mile 85 and 120 hard snow was encountered that permitted the tank to travel 16 to 20 mph. In virgin snow the medium tank M48 speed was reduced to one-half its speed on the trail.

* See U. S. Army Engineer Waterways Experiment Station, CE, *Comparison of Performance Characteristics in Snow of the Polecat and Weasel*, Miscellaneous Paper No. 4-282 (Vicksburg, Mississippi, August 1958).

Nevertheless, the medium tank M48 was found to be quite maneuverable in virgin snow also. A tight forward or reverse turn could be made with a turning radius ranging from 20 to 46 ft, depending upon the hardness of the snow. Except in soft, dry and wet snow the medium tank M48 could easily turn 180 degrees on the trail in neutral steer. On hard trail snow, a 360-degree turn could be made. Turning in neutral steer in virgin snow was limited because of the deeper ruts made, which caused the snow to pile up to the sides of the medium tank M48 rapidly. Neutral-steer position in virgin snow would permit the vehicle to turn 20 to 40 degrees.

The economy of operating a medium tank M48 in snow is very poor. Accurate figures on fuel consumed could not be compiled because of the difficulties encountered with the fuel filter (discussed in the next paragraph). It was estimated that the tank consumed 10 gal per mile (i.e., traveled 0.1 mile per gallon). This is about four times the normal consumption rate. Actual running time from Fist Clench to the edge of the ice cap was 29 hr and 40 min, which represented an average rate of speed of 7.4 mph.

Difficulties encountered
and possible solutions.

68. The following mechanical difficulties were encountered on the trip to Fist Clench and return: (a) failures in the diaphragms of the fuel pumps, (b) shorting out of the main engine generator; and (c) failure of the igniters of heaters inside the tank after about 10 hr of operation. Another difficulty encountered was that of fuel filter stoppage. The fuel used in this operation was stored in 50-gal drums that had been delivered to Greenland in about 1951. The long period of exposure of these fuel drums resulted in an accumulation of water therein. This water was agitated when the fuel drums were transported by sled and became dispersed throughout the container. As soon as air temperatures became cold enough to freeze water, ice needles formed in the fuel. In order to minimize the effects of water or ice crystals, 5 to 10 per cent by volume of methyl alcohol was added to the fuel. This was not completely satisfactory because sufficient ice crystals and water remained dispersed in the fuel to choke the fuel filter to the point where sufficient fuel did not pass to the carburetors, thus causing the engine to miss. After each refueling the filter was removed, and the filter container and some of the fuel in the tanks were drained. On several occasions this operation had to be done three times. Naturally, the solution to the problem is to use waterless fuel, but this may not always be possible in arctic operations. It is believed that heating the fuel and carburetors and perhaps selecting a filter-carburetor combination that will permit water to pass without affecting engine operation would be a satisfactory solution. Because of the high altitudes encountered near the center of the ice cap, superchargers and special carburetor jets would result in more efficient operation.

PART VI. CONCLUSIONS AND RECOMMENDATIONS

69. The following conclusions and recommendations are based on an analysis of the data presented in this report and visual observations made in the field.

XXV. CONCLUSIONS

Snow properties.

70. In regard to snow properties, it is concluded that:

a. Because most snow types compact and then shear abruptly when being tested by a strength-indicating instrument, difficulties are encountered in obtaining strength measurements with most types of profile strength-measuring instruments. In order to obtain a good measure

of snow strength, a large number of carefully taken readings are needed so that a reliable average strength value can be determined.

b. The presence of ice lenses or hard compacted snow layers within the snowpack results in a wide range of readings. If these layers can be penetrated and are not numerous, readings obtained in them should be excluded when determining an average strength value for the snowpack.

c. The highest before-traffic strength readings are usually obtained in the early spring when the snow is wind-packed and dry, or in moist or wet snowpacks that have refrozen. As the temperature of the snowpack approaches 0 C, strength decreases, density increases with an increase in snow wetness, and grain size increases. Moist and wet snow gave higher after-traffic strength readings than did dry snow.

d. Strength and density measurements after traffic vary with respect to the number of passes applied, the initial strength of the snow, and the load applied. The magnitude of the change is dependent upon such factors as the contact pressure of the vehicle, gross vehicle weight, number of passes applied, and the grain size and wetness of the snow.

e. All wet, moist, and the softer dry snows increased in strength with compaction; but hard to very hard dry snow may lose a slight amount of strength when compacted because the bond between the snow grains is destroyed.

Snow trafficability.

71. In regard to measurement of the trafficability of snow, it is concluded that:

a. The snow conditions tested in Greenland during the summers of 1955 and 1957 did not produce sufficient immobilizations to establish limiting snow conditions for the vehicles tested; therefore, one of the primary objectives of the study could not be fulfilled. However, it was found that important vehicle-performance parameters, such as depth of rut created by one pass of a vehicle, the maximum drawbar load a vehicle could tow, and sliding friction, can be correlated with physical snow-property measurements.

b. The results of snow measurements made in virgin snow gave the best vehicle- and sled-performance correlations. For operational purposes, it is possible to predict vehicle and sled performance from a few simple snow measurements.

c. It was found that the best correlations were obtained between vehicle performance and snow-property measurements by considering average values for the 0- to 6-in. or 0- to 12-in. layers, depending upon the type of test and vehicle weight, and by separating the snow conditions tested into classes on a basis of snow wetness.

d. Age-hardening greatly increases the bearing capacity of the snow, but a corresponding increase in traction capacity is not apparent.

e. The stress pattern produced in snow by traffic can be determined by means of a smoke-stain technique.

Vehicle performance.

72. In regard to vehicle performance in Greenland, it is concluded that:

a. Slopes and crevasses found along the ramps and hilly areas extending some 15 to 25 miles inland are the primary obstacles to tracked-vehicle mobility on the ice cap.

b. Except for areas of very soft snow found occasionally several hundred miles out on the ice cap, wet soft snow encountered 15 to 25 miles from the edge of the ice cap, and occasional wind-etched surfaces, the vehicles presently used in Greenland can travel at or near half their design maximum speeds.

c. For the same value of a given snow-property measurement and same snow-wetness class, the depth of rutting is directly dependent upon the nominal ground-contact pressure of the vehicle.

d. The first pass made by a vehicle appears to be the most critical. Because of decreased rolling resistance and a firmer surface (due to snow compaction effected by first pass) on which to develop the necessary traction, successive passes are less difficult.

e. For wheeled vehicles without tow loads:

(1) Because most snow conditions were critical for wheeled vehicles, the data collected provided little opportunity to correlate snow conditions with vehicle performance.

(2) On the basis of snow-property measurements, snow conditions that would permit passage of the 2-1/2-ton truck M47 could not be distinguished from snow conditions that would not permit passage. However, rut depth could be correlated with vehicle performance on a "go" or "no go" basis.

(3) The mobility of the 2-1/2-ton truck M47 was materially improved when the tire pressure was reduced to 10 psi. Tire pressure, however, had little or no effect on rut depth.

(4) Conventional wheeled vehicles cannot operate on the Greenland Ice Cap.

f. For tracked vehicles without tow loads:

(1) Snow conditions tested were adequate for several (at least 10) passes of all tracked vehicles tested (ground-contact pressures ranged from 1.0 to 10.5 psi). Regardless of vehicle contact pressure, continued traffic up to 40 or 50 passes produced ridges and swales in the rut surface that made it necessary to decrease the speed of the test vehicle.

(2) For the same ground pressure, the depth of the stress bulb was dependent upon the initial strength of the snow. For a range of ground pressures, the depth of the stress bulb was dependent upon gross vehicle weight.

(3) There is a definite relation between the strength change that results due to traffic and vehicle cone index. The ratio is dependent upon the amount of traffic applied, snow wetness, and ground-contact pressure.

(4) The rolling resistance for the tracked vehicles ranged from 1.5 to 7.5 per cent of the vehicle weight when operating in dry snow, and from 10 to 14 per cent of the vehicle weight when operating in wet snow.

g. For tracked vehicles with tow loads:

(1) Vehicle-performance relations could be determined on the basis of snow wetness. The best towing performance was obtained with the vehicles operating in moist snow.

(2) Drawbar pull increases as snow strength increases until an optimum condition is reached, after which the drawbar pull decreases as the snow strength increases.

(3) For all snow wetnesses, the LGP tractors gave the best traction performance

in terms of per cent of vehicle weight, followed by the weasel M29C, the otter M76, and then the high-ground-pressure vehicles (M5A4, M4, and M48).

(4) The maximum drawbar pull usually occurred at track slippages in the order of 10 to 30 per cent, with the per cent slip being higher in wet snow than in dry snow. With respect to track slippage, the LGP tractors attained their maximum drawbar pull at less slip than the other vehicles tested.

(5) The tractive coefficients for the vehicles tested ranged from 20 to 60 per cent of the vehicle's weight.

h. For towed vehicles:

(1) For a given snow class, the changes in physical snow properties that occur as a result of compaction by the towing tractor apparently have a tendency to produce a narrow range in kinetic friction even though the virgin-snow property measurements may show a fairly wide range.

(2) The coefficients of kinetic and static friction were highest for dry snow and about the same for moist and wet snow.

(3) The coefficient of kinetic friction for Teflon-coated runners operating on dry snow was approximately one-half that of steel runners, and values of kinetic friction coefficients for runners coated with Kel-F fall about halfway between those for steel and Teflon-coated runners.

(4) Average static friction values determined for all snow wetnesses were approximately three to five times the average kinetic friction for steel runners, and two to three times greater than the average kinetic friction for the plastic-coated runners.

(5) An increase in the contact pressure of a runner surface for the range of loads and speeds tested had little or no effect upon kinetic friction.

(6) The Otaco sleds required about 4 per cent less pull than the tracked Athey wagon trailer in dry snow and about 33 per cent less pull in moist and wet snow. A reduction in the ground-contact pressure of the tracked trailer would improve its performance to approximately that of the sleds.

Instruments.

73. In regard to the instruments used in the tests, it is concluded that:

a. All instruments used in obtaining the desired snow data were, in general, adequate from the serviceability standpoint; however, certain instruments (namely, the cone penetrometer, vane shear, and Ramm penetrometer) were more efficient than the others in collecting the necessary data.

b. Reasonable correlations were obtained between vehicle performance and snow-property measurements. Cone index gave the best over-all correlations with vehicle performance and also with other snow-property measurements.

c. The electrical and electronic equipment used to measure drawbar pull-slip data performed satisfactorily.

XXVI. RECOMMENDATIONS

74. It is recommended that:

a. Trafficability studies be continued in Greenland to test new vehicles.

b. Virgin snow measurements be used to evaluate the trafficability of a snow surface and one-pass traffic be established as the criterion for defining a "go" or "no go" snow condition.

c. Methods of improving traction systems on vehicles as well as the effects of other vehicle characteristics, such as the dynamic center of gravity when a vehicle is towing a load, etc., be investigated.

d. Since most snow conditions on the ice cap offer sufficient bearing capacity and are deficient in traction capacity, the development of vehicles with thrust type power be investigated.

e. The cone penetrometer be accepted as the most practical field instrument for measuring snow trafficability.

f. Since the prediction of snow trafficability by noncontact means is part of the over-all project, pilot studies be initiated to determine if meteorological data can be used to predict the seasonal changes that occur in such snow properties as strength, grain size, and wetness

Table 1

Daily Surface Weather Observations

24 June to 11 August 1955

Location Mile	Date	Temperature °F Max	Min	Mean Hourly	Relative Humidity, % Max	Min	Mean Hourly	Wind, mph Max	Min	Mean	Avg Sky Cover	Precipitation Type
7	6/24	29	24	26	98	64	86	10	2	6	Overcast	
	6/25	25	23	24	100	94	97	20	9	15	Overcast	Blowing snow
	6/26	33	27	30	91	77	79	12	4	8	Clear	
	6/27	35	31	32	82	85	81	9	4	7	Cloudy	
	6/28	38	33	35	92	75	82	10	2	7	Cloudy	
	6/29	38	36	37	92	83	87	12	3	8	Clear	
	6/30	39	38	38	76	69	73	10	2	5	Clear	
	7/1	40	36	36	76	69	74	12	8	10	Clear	
	7/2	39	37	39	79	76	78	10	8	9	Clear	
	7/3	40	33	39	90	74	80	4	2	4	Clear	
40	7/5	33	26	32	100	92	96	--	--	3	Clear	
	7/6	34	26	32	100	92	96	5	1	3	Overcast	
	7/7	28	22	25	100	96	98	27	20	25	Overcast	
152	7/10	23	20	24	98	92	96	--	--	15	Overcast	
	7/11	30	24	28	74	55	65	--	--	6	Overcast	Snow
220	7/13	23	20	22	100	98	99	15	10	12	Partly cloudy	
	7/14	23	11	16	96	78	90	--	--	--	------	
	7/15	24	11	20	100	90	96	15	10	12	Overcast	Snow
	7/16	29	18	22	100	98	100	--	--	--	Overcast	Snow
	7/17	23	12	20	100	88	96	--	--	8	Overcast	Snow
	7/18	23	12	20	100	88	94	--	--	5	Partly cloudy	
	7/19	26	6	18	100	83	90	--	--	--	------	
	7/20	23	6	16	88	82	85	6	6	6	Clear	
	7/21	18	5	14	95	80	90	--	--	--	Partly cloudy	
	7/22	18	12	18	95	90	93	--	--	10	Overcast	
150	7/25	24	17	20	100	100	100	25	17	20	Clear	
	7/26	23	11	20	100	82	98	15	1	10	Overcast	
	7/27	26	11	18	84	74	80	10	10	10	Clear	
	7/29	--	--	--	--	--	--	25	--	--	Overcast	
	7/30	--	--	--	--	--	--	10	5	7	Overcast	
70	7/31	22	8	18	100	92	98	7	5	6	Overcast	
	8/1	22	12	17	100	78	90	--	--	3	Clear	
	8/2	22	18	--	--	--	--	18	8	10	Overcast	
32	8/3	32	31	31	--	--	--	15	5	10	Partly cloudy	
	8/4	30	28	30	100	100	100	40	20	35	Overcast	Snow
	8/5	40	28	35	100	55	75	7	5	6	Overcast	
	8/6	45	30	33	85	45	70	2	2	2	Clear	
	8/7	38	37	36	90	80	85	6	2	4	Partly cloudy	
	8/8	37	35	36	95	78	86	--	--	1	Cloudy	
8	8/9	35	33	34	90	85	88	--	--	16	Clear	
	8/10	32	32	32	100	100	100	12	8	10	Overcast	Drizzle
	8/11	32	32	32	100	100	100	15	5	5	Overcast	Drizzle

Note: Temperature, relative humidity, wind speed, and sky cover measurements were made at 4-hour intervals between 8 AM and 8 PM.

Table 2

Daily Surface Weather Observations, Mile 30

3 May to 5 July 1957

	Temperature °F			Wind, mph				
Date	Max	Min	Mean	Max	Min	Mean	Avg Sky Cover	Precipitation Type
5/3	0	-10	-5	--	--	--	------	
5/4	12	0	6	--	--	--	------	
5/5	19	-1	9	--	--	--	------	
5/6	26	10	18	--	--	--	------	
5/7	9	2	4	--	--	--	------	
5/8	14	0	7	--	--	--	------	
5/9	20	3	12	--	--	--	------	
5/10	22	8	15	--	--	--	Partly cloudy	
5/11	31	17	24	8	C	8	Cloudy	
5/12	34	16	25	6	C	3	Partly cloudy	
5/13	30	12	21	6	C	8	Partly cloudy	
5/14	32	20	26	12	6	7	Partly cloudy	
5/15	37	23	30	9	C	7	Clear	
5/16	40	23	31	12	6	10	Clear	
5/17	38	26	32	12	9	6	Clear	
5/18	40	22	31	6	5	5	Clear	
5/19	37	18	27	6	4	5	Clear	
5/20	33	19	26	4	C	2	Clear	
5/21	28	17	22	8	C	5	Clear	
5/22	42	18	30	C	C	5	Clear	
5/23	38	17	27	6	C	3	Clear	
5/24	43	22	32	8	C	4	Clear	
5/25	34	19	26	5	C	--	Partly cloudy	
5/26	35	20	27	20	--	--	Clear	
5/27	27	16	21	7	C	5	Cloudy	
5/28	23	14	18	12	4	9	Cloudy	
5/29	24	10	17	5	C	--	Partly cloudy	
5/30	21	12	16	10	--	--	Cloudy	
5/31	22	10	16	8	C	3	Partly cloudy	
6/1	33	12	22	C	C	5	Clear	
6/2	40	12	26	13	4	9	Partly cloudy	
6/3	--	--	--	36	26	23	Overcast	Blowing snow
6/4	--	--	--	--	--	11	Overcast	Blowing snow
6/5	25	19	22	10	C	16	Cloudy	Snow, blowing snow
6/6	20	19	20	32	5	12	Overcast	Blowing snow
6/7	34	18	26	4	C	3	Cloudy	
6/8	42	25	33	4	C	4	Partly cloudy	
6/9	42	25	33	6	C	4	Clear	
6/10	40	30	35	16	8	16	Partly cloudy	
6/11	36	29	32	25	12	12	Partly cloudy	
6/12	42	32	37	7	4	8	Clear	
6/13	44	34	39	6	3	2	Clear	
6/14	45	33	39	--	C	4	Partly cloudy	
6/15	37	31	34	7	5	5	Clear	
6/16	38	30	34	--	--	13	Clear	
6/17	36	33	34	14	8	8	Clear	
6/18	36	28	32	28	7	19	Clear	
6/19	36	28	32	11	10	7	Cloudy	Blowing snow
6/20	52	31	41	C	C	6	Clear	
6/21	46	36	41	--	--	10	Partly cloudy	
6/22	36	33	34	25	5	14	Overcast	Blowing snow
6/23	40	35	38	7	2	8	Cloudy	
6/24	41	35	38	8	5	16	Partly cloudy	
6/25	34	31	32	25	15	21	Overcast	Blowing snow
6/26	36	32	34	17	16	9	Overcast	Blowing snow, rain, snow
6/27	38	27	32	6	3	12	Overcast	
6/28	45	24	34	C	C	6	Clear	
6/29	38	30	34	8	2	5	Partly cloudy	
6/30	38	30	34	3	C	15	Clear	
7/1	--	--	--	12	10	3	Partly cloudy	
7/2	--	--	--	2	1	10	Partly cloudy	
7/3	--	--	--	5	1	10	Clear	
7/4	--	--	--	4	2	15	Clear	
7/5	--	--	--	4	2		Clear	

Table 3

Vehicle Data

Self-Propelled Wheeled Vehicles

Vehicle	Test Weight lb	Tires Size	Tires Ply	Clearance in.	Engine Type	Engine Brake hp	Transmission Type	Remarks
2-1/2-ton 6x6, M47	13,540	11.00x20	12	13.9	Gasoline	127	Synchromesh	Brake hp at 3400 rpm
Tournadozer	36,000	21.00x25	16	21.0	Diesel	186	Tournamatic, constant mesh clutch operated	Brake hp at 1800 rpm
Terracruiser 8x8, XM357	29,500	42 by 60 by 10 in.	--	----	Gasoline	340	Torqueamatic	Maximum brake hp at 3200 rpm. Tire pressure 3-5 psi. Ground-contact pressure empty, 3.84 psi

Self-Propelled Tracked Vehicles

Vehicle	Test Weight lb	Track, in. Contact Length	Track, in. Width	Track, in. Shoe Length	Contact Pressure psi	Bogies on Ground Per Side	Clearance in.	Engine Type	Engine hp	Transmission Type	Remarks
Weasel, M29C	5,450	81.0	20	4.50	1.68	8	12.0	Gasoline	65	Mechanical	Brake hp at 3600 rpm
Sno-Cat, model 743	8,230	84.0	24	----	1.02	-	15.5	Gasoline	180	Fluid drive	Pontoon-ladder track
Otter, M76	9,960	96.5	30	4.00	1.72	4	16.8	Gasoline	127	Fluid drive	Brake hp at 3200 rpm
Standard D6 tractor	18,340	96.5	30	6.75	3.17	6	12.5	Diesel	55	Mechanical	Net hp at 1400 rpm
Hi-speed tractor, M5A4	25,440	117.5	17	5.50	6.37	5	19.8	Gasoline	207	Mechanical	Brake hp at 2900 rpm
LGP-D7 tractor	26,200	129.5	35	9.25	2.89	7	16.0	Diesel	80	Mechanical	Net hp at 1000 rpm
Hi-speed tractor, M4	31,400	131.5	17	6.00	7.02	5	20.3	Gasoline	190	Torque converter	Brake hp at 2900 rpm
LGP-D8 tractor	66,000	170.0	54	8.00	3.59	9	12.0	Diesel	210	Torque converter	Maximum hp at 1700 rpm
Medium tank, M8	96,430	164.0	28	10.50	10.50	6	19.0	Gasoline	810	Hydramatic	Maximum hp at 2800 rpm

Towed Vehicles, Tracked

Vehicle	Test Weight lb	Track, in. Contact Length	Track, in. Width	Track, in. Shoe Length	Contact Pressure psi	Bogies on Ground Per Side	Clearance in.	Remarks
Athey wagon model BT 898-4	22,460	44.0	14.5	6.8	17.6	2	15	Empty weight 10,230 lb

Towed Vehicles, Sleds

Vehicle	Test Weight lb	Runner, in. Contact Length	Runner, in. Width	Contact Pressure psi	Clearance in.	Remarks
Otaco, 10-ton capacity	19,340	80	24	2.5	7.0	Payload 5,000 lb
Otaco, 10-ton capacity	27,890	80	24	3.6	7.0	Payload 9,960 lb
Otaco, 10-ton capacity	38,190	80	24	5.0	7.0	Payload 30,060 lb

Table 4

Example of Field Data Collected and the Data Ruled Out in the Averaging Process

TEST LOCATION	Mile 150
TEST NO.	1
TEST DATE	25 July 1955
TEST VEHICLE	Standard D6 (30-in. pads)
AIR TEMPERATURE	17 F
SLOPE	0%

TEST DESCRIPTION

A self-propelled test with one-way traffic. The vehicle traveled in low gear. After one pass the rut depth was about 6 in. and uneven due to the uneven wind-blown surface. Little change occurred in rut appearance after one pass, and after 10 passes rut depth had increased approximately 2 in. The vehicle completed 10 passes with ease.

CONE INDEXES

BEFORE TRAFFIC

Sta	Sfc L	Sfc R	3 L	3 R	6 L	6 R	9 L	9 R	12 L	12 R	15 L	15 R	18 L	18 R	24 L	24 R	30 L	30 R
0+00	4	2	14	4	1	6	11	14	11	14	12	22	12	22	10	22	14	8
0+05	6	4	20*	4	1	8	1	22	14	22	66*	24	44*	24	14	6	14	16
0+10	4	3	12	3	4	26*	12	46*	14	14	14	32*	14	60*	30	20	10	20
0+15	4	4	4	3	8	3	18	3	8	10	40*	22	42*	24	26	32	8	8
0+20	5	4	4	1	8	3	8	3	10	22	24	22	26	34	26	10	16	10
0+25	6	4	2	2	2	2	6	4	14	6	14	20	42*	42	22	26	8	24
0+30	3	5	5	7	7	5	11	11	11	14	17	14	17	26	14	6	8	6
0+35	3	5	8	9	3	6	9	16	16	16	20	16	20	16	8	20	38	6
0+40	5	6	1	4	3	4	7	4	13	22	20	18	20	18	10	8	26	6
0+45	4	4	16	22*	3	2	7	8	11	18	18	18	18	8	18	8	18	6
0+50	4	4	26	4	1	4	7	12	9	12	14	14	20	14	14	26	8	8
0+55	3	2	1	10	4	1	8	9	22*	12	14	12	14	22	14	6	6	6
0+60	5	5	1	3	1	5	7	14	31*	42*	14	14	14	14	14	8	6	8
0+65	8	3	1	3	4	5	12	7	10	38*	12	14	14	14	14	8	16	6
0+70	4	4	1	4	4	4	28*	14	10	16	10	14	10	14	10	4	6	18
0+75	4	6	1	2	7	2	1	8	8	10	12	10	10	14	18	50*	4	34*
0+80	3	5	5	11	11*	11	3	6	9	14	9	12	11	12	19	16	9	8
0+85	4	6	10	8	12*	4	6	4	8	10	14	14	16	14	14	14	12	8
0+90	4	4	10	8	1	2	4	10	5	38*	12	16	12	16	12	8	8	14
0+95	6	4	12	2	1	2	9	16	9	32*	9	20	18	20	8	6	22	12
1+00	6	6	9	2	1	4	2	12	6	34*	14	12	14	12	14	8	28	8
	95	88	114	88	64	83	149	197	196	242	273	328	280	380	337	264	247	206
Avg	4	4	6	4	3	4	7	10	10	15	14	16	16	19	16	13	12	10
Avg	4		5		4		8		12		15		18		14		11	

1 PASS

Sta	Sfc L	Sfc R	3 L	3 R	6 L	6 R	9 L	9 R	12 L	12 R	15 L	15 R	18 L	18 R	24 L	24 R	30 L	30 R
0+00	4	4	20	12	26	24	34	20	24	28	24	44	24	30	14	12	62	28
0+05	8	4	16	18	36	28	18	30	18	40	26	26	28	20	28	14	98	60
0+10	8	3	22	18	40	30	22	32	34	20	20	30	20	20	42	40	110	110
0+15	6	5	20	30	22	40	24	24	26	25	32	50	32	28	36	20	76	60
0+20	4	4	32	10	28	33	26	35	26	22	22	40	22	25	22	18	64	50
0+25	8	4	22	20	34	40	82*	34	24	22	24	18	24	20	24	40	18	65
0+30	12	4	30	20	14	30	28	18	76*	40	22	30	12	45	22	30	14	120
0+35	9	5	18	35	18	30	16	15	16	20	16	20	16	15	36	40	62	80
0+40	5	4	15	10	17	25	24	15	24	30	14	20	14	50	54	40	68	70
0+45	6	5	20	15	19	25	18	35	18	20	14	20	10	20	20	30	130	60
0+50	8	5	26	25	32	40	18	45	18	15	18	20	14	20	14	25	110	70
0+55	6	5	22	25	48	35	22	55	18	60*	24	20	24	15	28	60*	96	50
0+60	10	10	24	15	24	30	34	55	34	25	34	25	22	25	24	40	26	**
0+65	8	4	30	20	22	30	16	50	16	28	24	40	28	30	32	60*	130	40
0+70	8	8	24	25	52	30	20	40	20	70*	40	20	76*	30	20	40	130	100
0+75	8	8	28	30	52	40	42	70*	24	20	24	20	24	25	24	40	8	20
0+80	5	4	28	20	20	30	52	45	10	60*	10	15	40	15	54	30	130	60
0+85	8	10	22	25	34	40	24	55	14	36	24	20	24	20	36	50	96	60
0+90	12	5	38	10	32	30	24	50	24	30	16	30	32	85*	92*	20	24	20
0+95	8	8	32	30	48	40	20	50	20	60*	20	30	26	30	120*	40	**	35
1+00	6	10	24	25	34	40	18	40	18	20	18	40	52	35	100*	50	**	65
	197	119	523	438	658	695	500	743	426	432	474	577	488	518	532	619	1432	1158
Avg	7	6	25	21	31	33	25	37	21	24	23	27	24	26	30	33	76	61
Avg	6		23		32		31		22		25		25		32		68	

10 PASS

Sta	Sfc L	Sfc R	3 L	3 R	6 L	6 R	9 L	9 R	12 L	12 R	15 L	15 R	18 L	18 R	24 L	24 R	30 L	30 R
0+00	10	8	28	52	74	110	42	125	34	25	24	30	24	18	36	20	82	65
0+05	18	12	78	40	110	110	28	125	28	55	16	20	16	18	34	30	120*	110
0+10	16	8	78	62	96	115	26	80	26	35	26	40	30	30	30	50	30	**
0+15	22	20	104	60	110	70	28	45	28	35	28	25	94*	25	10	50	10	65
0+20	4	3	87	25	80	30	120	25	130*	25	42	20	40	15	30	20	28	50
0+25	16	8	110	45	34	110	34	45	16	60	18	25	10	25	38	25	38	130*
0+30	22	15	120	90	110	125	90	30	10	25	40	15	40	18	30	18	30	200*
0+35	18	10	110	100	76	170*	34	130*	34	35	34	30	66*	20	70	75	80	**
0+40	26	18	86	80	84	120	116	60	16	20	16	20	36	28	120*	90	16	**
0+45	24	8	196*	20	110	90	18	115	18	40	18	35	18	20	76	30	**	**
0+50	16	6	36	40	34	70	34	80	34	105	26	30	26	18	26	25	**	**
0+55	16	8	10	125	26	140*	56	85	54	25	60	50	20	40	36	35	**	**
0+60	28	12	62	115	60	100	92	145*	30	25	30	30	30	30	**	**	**	15
0+65	14	15	32	30	54	105	110	130*	90	100	35	28	35	30	30	**	10	40
0+70	25	15	85	95	60	60	110	170*	50	25	32	40	34	30	**	120*	**	130*
0+75	22	15	100	100	60	95	35	125	40	10	82	20	31	30	**	130*	**	60
0+80	42	18	94	125	102	50	32	105	52	225*	18	20	18	30	18	40	**	50
0+85	38	40	120	120*	110	120	120	60	26	120	32	30	34	25	34	40	10	18
0+90	32	8	52	39	34	105	120	125	120*	30	42	20	44	40	110	70	**	15
0+95	32	30	64	25	64	105	16	25	32	75	**	20	**	45	**	15	**	20
1+00	32	25	70	115	120	116	130	80	110*	20	130*	20	36	30	**	80	**	15
	473	307	1516	1372	1508	1526	1411	1355	618	770	615	565	548	562	608	733	334	523
Avg	23	15	76	64	72	96	67	80	34	41	32	27	30	27	41	43	33	44
Avg	19		72		84		74		38		30		28		42		38	

COMPACTION CHARACTERISTICS

BEFORE TRAFFIC

STA 0+25 RIGHT TRACK — DEPTH 0-TO 12-IN.

	0 [illegible]			5 [illegible]			1? [illegible]			20 [illegible]		
In	6	6	6	6			12			23		
	3	3	3	14			16			24		
	2	2	2	24			36			23		
	8	8	8	24			32			40		
	2	2	2	14			30			28		
	2	1	2	10			24			18		
	3	4	4	12			22					
	8	12	10									
	14	16	15									
			52	104			172			174		
Avg			5.8			149			246			290
	2.57						4.24			5.00		
Comp in	2.75						3.25			3.76		
	30 [illegible]			38 [illegible]			60 [illegible]			— [illegible]		
In	12			15			24					
	36			44			42					
	38			48			54					
	42			68			70					
	40			40			88					
	22											
	200			215			278					
Avg			33.3			434			556			
	5.74						9.59					
Comp in	4.25			4.50			4.75					

REMOLDING INDEXES

BEFORE TRAFFIC

STA 0+75 RIGHT TRACK — DEPTH 0-TO 12-IN

	0 [illegible]			30 [illegible]			0 [illegible]			30 [illegible]		
In	6	6	6	12			6	8	7	22		
	2	4	3	32			4	4	4	32		
	4	6	5	47			8	7	8	44		
	10	12	11	50			7	12	10	58		
	8	6	7	22			6	4	5	24		
	6	3	4				4	4	4			
	2	2	2				3	4	4			
	2	4	3				4	6	6			
	3	8	6				8	8	8			
			47			163			56			180
Avg			5.2			32.6			6.2			36.0
	6.27						5.81					
Comp in	4.75						4.62					

STA 0+25 RIGHT TRACK — DEPTH 0-TO 12-IN.

	0 [illegible]			25 [illegible]			0 [illegible]			50 [illegible]		
In	4	3	4	8			4	6	5	8		
	2	3	2	28			4	4	4	24		
	6	6	6	48			8	6	7	32		
	14	12	13	50			3	3	3	54		
	3	3	3	24			2	2	2	52		
	2	2	2				2	2	2	24		
	6	2	4				4	3	4			
	10	4	7				12	8	10			
	18	14	16				18	14	16			
			57			188			83			194
Avg			6.3			34.6			5.9			32.3
	5.02						5.47					
Comp in	4.62						4.50					

* Eliminated from averages.
** 320 and eliminated from averages.

(Continued)

Table 4 (Concluded)

SHEAR VANE, TORQUE IN INCH LBS.

[illegible]	[illegible]		[illegible]		[illegible]		18-24	
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
BEFORE TRAFFIC — LEFT TRACK								
[illegible]	10	5	50	5	90	5	110	5
[illegible]	20	8	30	5	40	0	110	5
[illegible]	10	9	60	5	90	5	90	5
[illegible]	20	5	30	5	70	5	90	5
[illegible]	5	0	50	0	80	0	60	0
[illegible]	10	0	60	5	90	5	80	5
[illegible]	10	0	40	5	30	5	10	0
[illegible]	20	0	30	0	80	0	20	0
[illegible]	40	0	30	0	40	5	80	5
[illegible]	20	0	40	5	60	5	80	5
[illegible]	10	0	40	5	90	0	50	0
Total	175	15	540	40	770	35	780	30
Avg	16	1	49	4	72	3	70	3
1-PASS								
[illegible]	60	10	90	5	100	0	70	5
[illegible]	70	20	120*	10*	90	5	30	5
[illegible]	80	10	80	5	80	5	60	10
[illegible]	70	10	80	5	60	5	80	0
[illegible]	80	20	80	10	70	5	100	5
[illegible]	100	20	80	10	140	5	30	5
[illegible]	60	10	90	10	90	5	100	0
[illegible]	70	10	50	10	40	10	130*	0
[illegible]	90	5	90	5	50	5	80	0
[illegible]	50	20	80	10	90	5	40	0
[illegible]	70	10	90	5	60	5	80	5
Total	780	145	810	75	780	35	770	55
Avg	71	13	81	8	71	5	71	3
10-PASSES								
[illegible]	60	10	100	5	70	5	130	5
[illegible]	130	20	160	10	50	5	120	5
[illegible]	170	20	200	20	70	5	70	5
[illegible]	110	30	100	5	40	5	100	0
[illegible]	130	30	80	10	70	5	70	5
[illegible]	100	20	90	10	50	5	130	0
[illegible]	110	20	140	10	50	5	120	5
[illegible]	120	20	260*	30*	40	5	80	0
[illegible]	100	10	80	5	60	5	150	0
[illegible]	190	30	100	20	50	5	100	0
[illegible]	150	40	130	20	120	20	100	10
Total	1390	240	1150	115	810	70	1160	35
Avg	126	22	115	12	61	6	105	3

RAMM HARDNESS

BEFORE TRAFFIC

STA 0+25 LEFT TRACK

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
					0					
1	1	0	0	0	3	3	1	-	1	3
1	1	1	0	0	3	0	2	-		
		1	5	1	5	2	2	2	4	6
		1	5	1	10	5	2	1	3	16
		1	5	1	20	10	2	0	2	20
		1	20	3	25	5	2	12	14	70
		1	20	4	30	5	2	16	18	90
		1	20	4	35	5	2	16	18	206
		1	20	5	40	5	2	20	22	
		1	20	7	45	8	2	28	30	Avg=7
		1	20	3	50	5	2	12	14	
		1	20	3	55	5	2	12	14	
		1	20	7	60	5	2	28	30	
		1	20	7	65	5	2	28	30	
		1	20	4	70	5	2	16	18	
		1	20	3	75	5	2	12	14	
		1	20	1	85	10	2	2	4	
		1	20	1	90	5	2	4	6	
1-PASS										
					0					
1	1	0	0	0	5	5	1	-	1	5
1	1	1	0	0	5	0	2	-	-	
		1	5	2	10	5	2	2	4	20
		1	20	2	15	5	2	8	10	50
		1	20	4	20	5	2	16	18	90
		1	20	5	25	5	2	20	22	110
		1	20	5	30	5	2	20	22	110
		1	20	7	35	5	2	28	30	385
		1	20	7	40	5	2	28	30	
		1	20	6	45	5	2	24	26	Avg=1[illegible]
		1	20	6	50	5	2	24	26	
		1	20	6	55	5	2	24	26	
		1	20	6	60	5	2	24	26	
10-PASSES										
					0					
1	1	0	0	2	1	1	1	-	1	1
1	1	1	0	0	1	0	2	-	2	—
		1	50	2	10	9	2	11	13	117
		1	50	3	15	5	2	30	32	160
		1	50	4	20	5	2	40	42	210
		1	50	2	25	5	2	20	22	110
		1	50	4	30	5	2	40	42	210
		1	50	6	40	10	2	30	32	800
		1	50	7	50	10	2	35	37	Avg=27
		1	50	7	60	10	2	35	37	

Note: Weighted average [illegible]

* [illegible]

CANADIAN HARDNESS

DEPTH, IN.	CANADIAN HARDNESS, g/cm²
BEFORE TRAFFIC — STA 0+50 LEFT TRACK	
0-5	200
5-8	30
8-11	300
11-16	4,000
16-19	2,000
19-21	2,200
21-30	3,000
1-PASS	
0-3	300
3-24	3,000
10-PASSES	
0-3	7000
3-6.5	1,500
6.5-12	2,000
12-16	3,000
16-22	3,000
22-24	1,500

2¼-IN TORQUE TUBE

TORQUE IN INCH LBS

BEFORE TRAFFIC

STA 0+50 LEFT TRACK

NORMAL LOAD PSI	INITIAL	RESIDUAL
MOVED POSITION		
1	6	3
2	9	4
3	10	5
4	24	8
5	25	8
NOT MOVED POSITION		
1	5	3
2	7	4
3	18	7
4	20	8
5	22	10

DROP CONE HARDNESS

[illegible]	[illegible]	L, gm	D, cm	P, cm	H, [illegible]
BEFORE TRAFFIC					
0+25 LEFT TRACK	1	2500	50	14	
	2	2500	50	13	
	3	2500	50	14	
	Avg	2500	50	13.7	
0+75 LEFT TRACK	1	2500	50	10	
	2	2500	50	11	
	3	2500	50	11	
	Avg	2500	50	10.7	
Avg.		2500		12.2	20
1-PASS					
0+25 LEFT TRACK	1	2500	50	12	
	2	2500	50	11	
	3	2500	50	13	
	Avg	2500	50	12.0	
0+75 LEFT TRACK	1	2500	50	11.5	
	2	2500	50	9.0	
	3	2500	50	10.0	
	Avg	2500	50	10.2	
Avg.		2500	50	11.1	29
10-PASSES					
0+25 LEFT TRACK	1	2500	50	12.5	
	2	2500	50	11.5	
	3	2500	50	10.5	
	Avg	2500	50	11.5	
0+75 LEFT TRACK	1	2500	50	13.0	
	2	2500	50	11.5	
	3	2500	50	12.0	
	Avg	2500	50	12.2	
Avg.		2500	50	11.8	22

[illegible]

SNOW CLASSIFICATION

Depth in. / cm	Grain Nature	Hardness	Wetness	Temp °C
3 / 10	Db (½-1½)	Kb	Wa	-9.5, -10.0
6	Db (½-1)			
9 / 20	Db (½-1½)	Ka		-12.0
12 / 30		Kb		-13.0, -12.0
15 / 40, 18, 21 / 50, 24 / 60, 27 / 70, 30	Db (½-1)	Kd		-13.5, -13.0, -13.0
30 / 80, 33, 36 / 90				-15.0

——— Denotes Ice

RUT PROFILE

Avg Rut Depth: 1 Pass 6.6 inches; 10 Pass 9.7 inches

Sta	Left Track Rut Reading, Pass No. 0	1	10	Left Track Rut Depth 1	10	Right Track Rut Reading, Pass No. 0	1	10	Right Track Rut Depth 1	10
[illegible]	168	227	238	62	95	171	215	239	42	64
[illegible]	165	249	251	84	94	170	213	239	43	69
[illegible]	175	245	262	70	87	177	229	267	62	90
[illegible]	182	246	280	64	98	181	238	265	5.7	84
[illegible]	182	249	260	67	78	183	226	264	5.1	79
[illegible]	185	244	252	59	67	187	237	259	6.0	82
[illegible]	206	256	271	50	65	195	239	263	44	68
[illegible]	208	256	270	48	62	200	248	263	48	63
[illegible]	234	263	294	59	90	203	248	287	45	84
[illegible]	204	230	31.5	66	111	201	256	276	55	75
[illegible]	203	232	31.7	71	114	197	262	286	65	89
[illegible]	210	278	29.0	68	80	208	239	300	71	92
[illegible]	219	295	309	76	90	216	282	307	66	91
[illegible]	215	289	310	74	95	227	293	308	66	81
[illegible]	229	300	311	71	82	227	294	308	67	78
[illegible]	208	296	314	88	106	213	233	310	60	97
[illegible]	206	292	307	86	101	203	288	300	85	97
[illegible]	178	282	308	104	130	190	273	293	83	103
[illegible]	238	316	327	78	99	230	300	324	70	94
[illegible]	246	326	344	80	98	241	306	302	65	61
[illegible]	239	[illegible]	320	70	81	230	290	305	6.0	75
Total				1495	1921				1266	1766
Avg				71	9.2				6.0	8.2

Table 5

Summary of Results of Lightweight, Self-Propelled, Tracked Vehicle Tests, 1955

Average Before- and After-Traffic Data

Item No.	Field* Test No.	Pass No.	Strength Measurements, 0- to 6-in. Depth: Cone Index	Vehicle Compaction Strength Index	25-blow: Compaction in.	25-blow: Rating Cone Index	Vane Shear Strength, psi: Initial	Vane Shear Strength, psi: Residual	Ram Hardness No.	Canadian Hardness g/cm^2	Torque Tube Shear Strength, psi, 2-1/4-in. Tube, Moved: Initial	2-1/4-in. Tube, Moved: Residual	2-1/4-in. Tube, Not Moved: Initial	2-1/4-in. Tube, Not Moved: Residual	5-in. Tube, Moved: Initial	5-in. Tube, Moved: Residual	5-in. Tube, Not Moved: Initial	5-in. Tube, Not Moved: Residual	Drop-Cone Hardness g/cm^3	Rut Depth in.	Snow Measurements, 0- to 6-in. Depth: Density g/cm^3	Temp °C	Snow Classification: Grain Nature	Snow Classification: Hardness	Snow Classification: Wetness
											Weasel M29C, Weight 5,450 lb														
1	7-11	0	11		2.5	57	1.6	0.20	6	550	10.8	2.5	6.6	2.4	10.1	3.0	11.7	3.5	32		0.45	0	Da	Kb^2Kc**	Wd
		1	17	1.5			3.1	0.48	9	4,000									45	1.4	0.60				
		10	40	3.6			6.3	0.68	12	3,500									30	1.8	0.62				
2	7-13	0	11		3.0	76	1.4	0.17	6	600	4.8	2.0	4.8	1.8	6.0	3.2	4.8	2.0	30		0.48	0	Da	Kc	Wd
		1	24	2.2			3.8	0.51	8	1,700									37	2.0	0.54				
		10	35	3.3			4.0	0.51	9	3,100									41	2.8	0.62				
3	8-2	0	11		2.4	42	1.7	0.07	4	1,500	---	---	---	---	---	---	---	---	210		0.44	0	Da	Kb	Wc
		1	18	1.6			4.2	0.17	15	4,000									---	1.3	0.49				
		10	24	2.2			2.9	0.17	14	25,700									---	1.8	0.51				
4	32-7	0	21		2.2	67	2.7	0.00	13	1,500	5.3	1.7	5.3	2.6	---	---	---	---	123		0.43	-1	Da	Kb	Wd
		1	22	1.0			2.5	0.07	19	1,500									---	1.4	0.51				
		10	29	1.4			3.0	0.07	22	2,800									---	1.5	0.53				
5	60-3	0	10		2.5	46	1.8	0.34	4	800	5.2	1.4	5.4	1.4	7.8	1.9	8.0	1.9	---		0.34	0	Db	Kb	Wc
		1	33	3.3			4.1	0.41	9	3,000									---	1.5	0.49				
		10	55	5.5			4.7	0.41	20	13,000									---	2.0	0.49				
6	70-6	0	4		4.5	11	1.5	0.00	3	670	3.2	1.3	3.0	1.0	---	---	---	---	9		0.24	-6	Fa^2Db**	Ka^2Kb	Wa
		1	18	4.5			2.2	0.00	12	1,300									---	2.4	0.35				
		10	19	4.8			2.9	0.14	15	2,500									---	3.6	0.40				
7	150-4	0	4		4.8	28	0.6	0.02	5	150	2.9	1.5	3.0	1.2	---	---	---	---	18		0.26	-8	Db	Kb	Wa
		1	9	2.2			1.1	0.07	7	650									18	3.0	0.35				
		10	12	3.0			0.6	0.02	13	980									44	3.6	0.40				
8	220-9	0	2		6.8†	20	0.0	0.00	1	50	---	---	---	---	---	---	---	---	2		0.15	-6	Fa^5Db	Ka^3Kb	Wa
		1	10	5.0			1.1	0.07	10	590									21	5.6	0.36				
		10	12	6.0			1.4	0.03	11	930									56	6.6	0.41				
9	31-1	0	8		3.8	21	0.8	0.03	11	300	---	---	---	---	---	---	---	---	---		0.29	-12	Db	Kb^2Kc	Wa
		1	10	1.2			1.6	0.07	10	200									---	2.3	0.33				
		10	12	1.5			1.6	0.07	10	300									---	2.7	0.42				
10	31-2	0	7		3.8	18	0.9	0.07	3	300	---	---	---	---	---	---	---	---	---		0.29	-12	Db	Kb^2Kc	Wa
		1	13	1.9			1.7	0.20	18	200									---	2.5	0.33				
		10	18	2.6			1.7	0.24	12	300									---	3.1	0.42				
11	31-5	0	5		4.9	26	0.8	0.00	3	400	---	---	---	---	---	---	---	---	---		0.24	-15	Db	Ka^3Kc	[illegible]
		1	13	2.6			1.2	0.05	19	430	---	---							---	3.6	0.38				
		10	30	6.0			2.4	0.29	14	500									---	4.2	0.37				
12	31-6	0	5		5.2	27	0.8	0.00	3	400	---	---	---	---	---	---	---	---	---		0.24	-15	Db	Ka^3Kc	Wa
		1	13	2.6			1.1	0.07	10	430	---	---	---	---	---	---	---	---	---	3.4	0.38				
		10	25	5.0			2.0	0.20	16	500	-								---	4.3	0.37				

(Continued)

* First number designates location of test site in miles from edge of icecap. Second number is test number at test site.

** Number designates the depth in inches at which a change in snow property occurred.

† Data from compaction characteristic curves.

Table 5 (Concluded)

Item No.	Field Test No.	Pass No.	Cone Index	Vehicle Compaction Strength Index	25-blow Compaction in.	25-blow Rating Cone Index	Vane Shear Strength, psi: Initial	Vane Shear Strength, psi: Residual	Ram Hardness No.	Canadian Hardness g/cm^2	Torque Tube 2-1/4-in. Tube Moved: Initial	2-1/4-in. Moved: Residual	2-1/4-in. Not Moved: Initial	2-1/4-in. Not Moved: Residual	5-in. Tube Moved: Initial	5-in. Moved: Residual	5-in. Not Moved: Initial	5-in. Not Moved: Residual	Drop-Cone Hardness g/cm^3	Rut Depth in.	Density g/cm^3	Temp °C	Grain Nature	Hardness	Wetness
											Sno-Cat 743, Weight 8,230 lb														
13	7-16	0	7		3.1	47	1.5	0.14	2	400	2.9	0.9	3.1	1.4	3.7	1.5	4.0	1.5	11		0.48	0	Dd	Kb	Wd
		1	35	5.0			3.5	0.65	10	500									25	1.7	0.55				
		10	76	10.9			9.7	0.55	23	2,700									32	2.7	0.63				
14	32-4	0	7		2.1†	21	0.4	0.00	2	900	---	---	---	---	---	---	---	---	35		0.47	0	Dd	Kc^5Kb	Wd
		1	18	2.6			3.0	0.24	8	2,000									---	1.4	0.53				
		10	20	2.9			5.2	0.27	6	2,000									---	1.3	0.56				
15	70-9	0	10		4.7	30	1.7	0.00	5	310	3.6	1.4	2.3	1.4	---	---	---	---	60		0.29	-7	Fa^2Db	Ka^1Kb	Wa
		1	13	1.3			1.6	0.03	15	910									---	1.0	0.34				
		10	19	1.9			2.1	0.07	12	1,000									---	1.9	0.38				
16	150-3	0	4		3.8	19	0.2	0.00	5	220	2.2	0.7	2.2	0.9	---	---	---	---	20		0.28	-8	Db	Kb	Wa
		1	6	1.5			0.5	0.03	9	400									---	1.2	0.34				
		10	14	3.5			1.1	0.07	8	400									---	3.0	0.41				
17	220-20	0	3		5.8†	22	0.5	0.00	1	100	1.7	1.3	---	0.7	---	---	---	---	4		0.18	-10	Fa^2Db	Ka	Wa
		1	8	2.7			1.4	0.14	5	330									21	3.6	0.31				
		10	11	3.7			1.4	0.07	5	1,100									20	4.6	0.43				
											Otter M76, Weight 9,960 lb														
18	7-5	0	71		1.9	114	7.0	1.13	60	2,700	3.5	2.6	5.7	3.5	3.2	2.4	3.3	2.2	43		0.41	-1	Fa^2Dd	Ka^2Kb^4Kd	Wd
		1	49	7.0			4.3	0.99	46	4,000									50	3.4	0.49				
		10	65	9.3			6.3	0.99	53	6,900									102	4.0	0.49				
19	7-6	0	89		1.4	160	7.8	1.19	52	3,300	2.5	1.6	3.8	2.1	2.3	1.7	2.9	2.2	128		0.48	-1	Fa^3Dd	Ka^3Kc^4Kd	Wd
		1	80	0.9			6.0	1.27	42	5,200									53	2.6	0.48				
		10	76	0.9			7.5	0.75	66	7,900									123	3.1	0.48				
20	8-3	0	16		2.9	78	2.3	0.10	6	1,500	---	---	---	---	---	---	---	---	210		0.44	0	Dd	Kb	Wc
		1	51	3.2			4.1	0.17	16	10,000									---	2.0	0.57				
		10	63	3.9			3.4	0.17	18	33,300									---	2.2	0.60				
21	32-5	0	22		2.6	97	1.1	0.07	10	5,000	5.2	1.9	5.9	2.8	---	---	---	---	123		0.46	0	Dd	Kb	Wd
		1	40	1.8			5.2	0.17	6	4,000									50	3.8	0.58				
		10	72	3.3			10.2	0.24	9	3,700									46	4.0	0.61				
22	70-3	0	6		4.5	24	1.1	0.03	3	460	2.1	1.3	2.2	1.3	---	---	---	---	---		0.29	-5	Fa^4Db	Ka^2Kb	Wa
		1	20	3.3			4.3	0.17	16	3,000									---	4.2	0.41				
		10	29	4.8			4.0	0.31	23	6,900									---	5.4	0.47				
23	122-1	0	8		3.4	14	1.0	0.00	11	300	2.7	2.2	3.2	2.2	---	---	---	---	37		0.34	-4	Db	Kb	Wa
		1	13	1.6			0.9	0.14	6	300									23	3.4	0.42				
		10	29	3.6			1.9	0.24	8	400									18	7.0	0.47				
24	150-6	0	7		4.0	36	0.8	0.03	3	380	2.8	1.5	3.7	1.7	---	---	---	---	25		0.23	-10	Db	Kb	Wa
		1	14	2.0			1.6	0.17	5	3,200									24	4.3	0.41				
		10	22	3.1			1.7	0.17	6	2,000									30	7.6	0.48				
25	220-6	0	1		---	9	0.0	0.00	1	10	1.8	1.2	2.1	1.2	---	---	---	---	1		0.12	-4	Fa	Ka	Wa
		1	17	17.0			1.5	0.17	10	700									42	8.4	0.38				
		10	21	21.0			1.9	0.24	10	500									52	10.6	0.46				

† Data from compaction characteristic curves.

Table 6

Summary of Results of Self-Propelled, Tracked Vehicle (Weighing More Than 10,000 lb) Tests, 1955

Average Before- and After-Traffic Data

Item No.	Field* Test No.	Pass No.	Strength Measurements: 0- to 12-in. Depth: Cone Index	Vehicle Compaction Strength Index	50-blows: Compaction in.	50-blows: Rating Cone Index	Vane Shear Strength, psi: Initial	Vane Shear Strength, psi: Residual	Ramm Hardness No.	Canadian Hardness g/cm²	Torque Tube Shear Strength, psi: 2-1/4-in. Tube: Moved: Initial	2-1/4-in. Tube: Moved: Residual	2-1/4-in. Tube: Not Moved: Initial	2-1/4-in. Tube: Not Moved: Residual	5-in. Tube: Moved: Initial	5-in. Tube: Moved: Residual	5-in. Tube: Not Moved: Initial	5-in. Tube: Not Moved: Residual	Drop-Cone Hardness g/cm³	Rut Depth in.	Snow Measurements: 0- to 12-in. Depth: Density g/cm³	Temp °C	Snow Classification: Grain Nature	Snow Classification: Hardness	Snow Classification: Wetness
											Standard D6 Tractor (30-in. Track Width), Weight 18,340 lb														
26	0-1	0	20		3.1	124	2.0	0.31	2	910	---	---	---	---	13.5	5.5	12.4	4.1	11		0.45	-1	Dd	$Kb^{6}Kd^{12}$**	Wd
		1	65	3.2			---	----	26	7,200									--	4.6	0.60				
		10	--				---	----	--	----									--	---	----				
27	0-2	0	16		3.2	158	2.3	0.24	14	910	---	---	---	---	13.3	5.5	11.3	4.1	18		0.45	-1	Dd	$Kb^{6}Kd$	Wd
		1	63	3.9			---	----	37	5,300									--	5.0	0.70				
		10	125	7.8			---	----	44	----									--	7.8	----				
28	7-1	0	15		4.0	159	2.3	0.26	8	760	---	---	---	---	---	---	---	---	--		0.42	0	$Fa^{3}Dd$**	$Kb^{6}Kc^{12}$	Wd
		1	70	4.7			9.6	1.00	24	17,500									37†	7.9	0.62				
		10	165	11.0			8.0††	0.55	119	15,000									--	9.6	0.57				
29	7-2	0	15		4.0	135	2.0	0.44	6	760	---	---	---	---	---	---	---	---	--		0.42	0	$Fa^{3}Dd$	$Kb^{6}Kc$	Wd
		1	65	4.3			8.7	1.08	22	7,600									37†	10.2	0.66				
		10	127	8.5			14.2††	----	48	28,300									--	12.2	0.60				
30	8-1	0	35		3.4	182	2.6	0.12	15	2,300	---	---	---	---	---	---	---	---	210		0.50	0	Dd	$Kd^{2}Kb^{6}Kd$	$Wd^{6}Wc$**
		1	51	1.5			6.8	0.27	27	4,600									71	4.8	0.56				
		10	94	2.7			9.6††	0.25	32	43,300									91	6.2	0.59				
31	32-1	0	33		2.6	102	2.5	0.05	35	2,500	---	---	---	---	---	---	---	---	35		0.48	0	Dd	$Kd^{7}Kb$	$Wd^{7}Wc$
		1	67	2.0			8.2	0.14	27	2,500									16	6.0	0.58				
		10	104	3.2			11.7	0.63	33	23,400									32	6.8	0.64				
32	32-2	0	24		2.8	48	1.9	0.10	12	2,400	---	---	---	---	---	---	---	---	--		0.46	-1	Dd	$Kb^{2}Kd^{8}Kb$	Wd
		1	55	2.3			8.9††	1.18	24	3,400									--	6.7	0.57				
		10	201	4.2			12.0††	0.99	33	16,900									--	7.5	0.63				
33	60-4	0	24		2.2	72	1.8	0.20	13	1,000	9.4	3.5	12.2	4.3	8.5	4.5	11.7	3.6	123		0.42	0	Db	Kb	Wc
		1	59	2.5			4.8	0.44	30	2,800									70	3.0	0.48				
		10	95	4.0			2.4	----	70	28,700									123	4.4	0.53				
34	70-1	0	8		4.5	42	1.6	0.00	8	450	3.1	2.1	3.6	2.1	---	---	---	---	9		0.32	-5	$Fa^{1}Db$	$Ka^{1}Kb$	Wa
		1	29	3.6			3.3	0.07	27	2,200									34	5.0	0.44				
		10	47	5.9			2.4	0.18	34	7,100									64	6.6	0.46				
35	70-2	0	12		4.8	60	1.4	0.02	6	480	3.1	2.1	3.6	2.1	---	---	---	---	--		0.32	-7	$Fa^{1}Db$	$Ka^{1}Kb$	Wa
		1	26	2.2			2.3	0.10	29	2,000									--	5.0	0.42				
		10	54	4.5			2.4	0.24	35	3,600									--	6.9	0.48				
36	122-2	0	8		3.8	24	1.2	0.02	11	250	4.7	3.2	4.9	3.7	---	---	---	---	20		0.34	-5	$Db^{10}Dd$	Kb	Wa
		1	34	4.2			4.2	0.20	28	810									--	4.8	0.43				
		10	67	8.4			4.2	0.28	40	1,920									--	6.6	0.44				
37	150-1	0	7		4.6	46	0.6	0.08	7	500	4.9	1.9	4.2	2.3	---	---	---	---	20		0.31	-11	Db	$Kb^{5}Ka^{8}Db$	Wa
		1	-24	3.4			2.8	0.36	13	2,400									29	6.6	0.44				
		10	58	8.3			4.3	0.58	27	3,600									22	8.7	0.46				
38	150-2	0	7		4.6	44	0.6	0.03	3	500	6.9	1.9	6.6	2.2	---	---	---	---	--		0.31	-11	Db	$Kb^{5}Ka^{8}Kb$	Wa
		1	23	3.3			2.0	0.27	16	2,000									--	6.6	0.42				
		10	72	10.3			4.4	0.68	42	5,000									--	8.6	0.48				
39	220-18	0	3		6.2‡	17	0.4	0.03	4	410	3.5	1.8	3.6	1.8	---	---	---	---	2		0.23	-9	$Fa^{3}Db$	$Ka^{3}Kb^{7}Kc^{10}Kb$	Wa
		1	30	10.0			2.8	0.38	15	1,800									18	8.2	0.43				
		10	50	16.7			2.9	0.38	35	4,800									25	11.0	0.47				

(Continued)

* First number designates location of test site in miles from edge of icecap. Second number is test number at test site.
** Number designates the depth in inches at which a change in snow property occurred.
† After second pass.
†† Several maximum readings were used in the average.
‡ Data from compaction characteristic curves.

Table 6 (Concluded)

Item No.	Field Test No.	Pass No.	Cone Index	Vehicle-Compaction Strength Index	50-blows Compaction, in.	50-blows Rating Cone Index	Vane Shear Strength, psi: Initial	Vane Shear Strength, psi: Residual	Ramm Hardness No.	Canadian Hardness g/cm^2	Torque Tube Shear Strength, psi: 2-1/4-in. Tube, Moved: Initial	2-1/4-in. Tube, Moved: Residual	2-1/4-in. Tube, Not Moved: Initial	2-1/4-in. Tube, Not Moved: Residual	5-in. Tube, Moved: Initial	5-in. Tube, Moved: Residual	5-in. Tube, Not Moved: Initial	5-in. Tube, Not Moved: Residual	Drop-Cone Hardness g/cm^3	Rut Depth in.	Snow: Density g/cm^3	Snow: Temp °C	Snow Classification: Grain Nature	Snow Classification: Hardness	Snow Classification: Wetness
											LGP-D7 Tractor, Weight 26,200 lb														
40	7-7	0	57		2.2	91	5.3	0.72	66	6,500	5.4	2.9	6.2	3.1	6.1	3.6	5.3	3.5	228		0.43	-1	Dd	$Kc^{2}Ke^{8}Kc$	Wd
		1	70	1.2			7.8††	1.28	29	7,700									62	5.6	0.48				
		10	154	2.7			14.2††	----	87	31,700									27	8.1	0.58				
41	7-8	0	59		1.9	89	4.8	0.42	55	9,200	5.3	2.8	5.9	3.4	6.0	3.6	5.2	3.4	218		0.44	-1	Dd	$Kc^{2}Ke^{8}Kc^{12}$	Wd
		1	68	1.2			8.6	1.28	51	7,800									44	7.6	0.46				
		10	148	2.5			14.2††	----	67	28,800									125	10.2	0.57				
42	7-12	0	18		3.2	117	1.9	0.24	9	550	8.3	3.3	7.6	3.3	11.0	4.2	7.5	---	30		0.49	0	$Dd^{7}Db$	$Kc^{7}Kb$	Wd
		1	65	3.6			8.9	1.72	35	5,700									76	6.7	0.60				
		10	143	7.9			14.2††	----	61	25,200									76	12.5	0.65				
43	60-1	0	27		3.7	248	2.3	0.40	15	900	7.7	2.7	9.3	2.3	15.2	3.7	12.2	2.6	15		0.36	-2	Db	$Kb^{6}Kc$	Wc
		1	74	2.7			8.4††	0.20	42	3,000									64	2.4	0.47				
		10	107	4.0			8.5††	0.41	36	38,700									190	3.8	0.52				
44	60-2	0	25		3.4	218	2.3	0.31	16	900	7.7	2.1	9.6	2.5	13.7	3.6	12.7	2.9	12		0.36	-2	Db	$Kb^{6}Kc$	Wc
		1	74	3.0			5.1	0.44	29	------									83	2.3	0.48				
		10	110	4.4			8.4	0.48	41	12,300									313	3.4	0.46				
45	122-3	0	10		3.8	40	0.9	0.00	23	160	3.9	3.1	4.6	3.1	---	---	---	---	32		0.34	-7	$Db^{10}Dd$	Kb	Wa
		1	32	3.2			1.9	0.22	28	500									32	3.8	0.42				
		10	65	6.5			4.8	0.20	29	4,700									83	6.6	0.41				
46	122-4	0	16		4.2	86	1.2	0.00	10	160	3.9	2.0	4.5	2.2	---	---	---	---	--		0.34	-7	$Db^{10}Dd$	Ka	Wa
		1	38	2.4			5.8	0.18	30	2,400									--	3.9	0.43				
		10	56	3.5			6.0	0.20	38	3,200									--	6.4	0.46				
47	220-1	0	4		5.0	24	0.4	0.05	4	130	5.3	1.9	7.2	2.2	---	---	---	---	6		0.27	-9	Db	Kb	Wa
		1	23	5.8			1.9	0.27	17	1,600									34	4.9	0.50				
		10	69	17.2			4.2	0.63	36	5,400									30	8.4	0.50				
48	220-2	0	5		5.0	30	0.6	0.03	6	130	5.3	1.9	7.2	2.2	---	---	---	---	--		0.27	-9	Db	Kb	Wa
		1	21	4.2			2.5	0.27	18	3,000									--	6.4	0.41				
		10	59	11.8			4.1	0.53	33	9,500									--	9.2	0.46				

†† Several maximum readings were used in the average.

Table 7

Summary of Results of Lightweight Self-Propelled, Tracked Vehicle Tests, 1957, Average Before- and After-Traffic Data

				Strength Measurements, 0- to 6-in. Depth									Snow Measurements 0- to 6-in. Depth				
					Vehicle	25-blow									Snow Classification		
Date	Item No.	Field Test No.	Pass No.	Cone Index	Vehicle Compaction Strength Index	Compaction in.	Rating Cone Index	Vane Shear Strength, psi Initial	Vane Shear Strength, psi Residual	Ram Hardness No.	Canadian Hardness g/cm^2	Rut Depth in.	Density g/cm^3	Temp °C	Grain Nature	Hardness	Wetness
Weasel M29C, Weight 5,450 lb																	
4 May	96	5	0	14		2.8	21	2.8	0.20	--	-----		0.33	-16	Db	Kd^{2}Kb^{5}Kd*	Wa
			1	17	1.2			2.9	0.30	--	-----	1.1	0.35				
			10	29	2.1			3.3	0.25	--	-----	1.4	0.38				
7 May	97	7	0	11		2.2	15	4.2	0.37	--	-----		0.34	-12	Db	Kd^{4}Kc	Wa
			1	14	1.3			3.9	0.43	--	-----	0.6	0.36				
			10	16	1.5			4.5	0.60	--	-----	1.2	0.37				
8 May	98	11	0	7		2.4	11	2.8	0.13	--	-----		0.32	-18	Db	Ka^{2}Kc^{4}Kd	Wa
			1	7	1.0			2.6	0.14	--	-----	1.3	0.37				
			10	12	1.7			2.6	0.12	--	-----	2.2	0.36				
18 May	99	41	0	17		1.9	29	2.4	0.14	12	330		0.35	-5	Db	Kb^{4}Kd	Wc^{4}Wa*
			1	21	1.2			3.3	0.28	20	850	1.0	0.42				
			10	25	1.5			3.5	0.12	24	2,500	1.4	0.42				
27 May	100	95	0	19		1.5	21	3.1	0.12	13	200		0.33	-5	Db	Kc	Wa
			1	17	0.9			2.6	0.12	17	1,250	0.7	0.42				
			10	19	1.0			3.0	0.12	23	1,750	1.4	0.47				
7 June	101	114	0	11		4.3	36	1.1	0.12	6	250		0.31	-6	Db	Kc	Wa
			1	15	1.4			2.4	0.12	13	2,000	1.3	0.38				
			10	16	1.5			3.1	0.19	13	2,250	2.4	0.37				
11 June	102	135	0	11		2.8	32	1.8	0.25	7	250		0.32	-2	Db	Kc	Wc^{5}Wa
			1	29	2.6			3.1	0.31	21	1,000	1.2	0.46				
			10	35	3.2			4.0	0.36	41	6,500	3.0	0.49				
20 June	103	170	0	5		4.4	50	1.2	0.19	3	200		0.50	0	Db	Ka^{1}Kd^{5}Kc	Wd
			1	29	5.8			3.6	0.77	12	2,000	3.8	0.62				
			10	42	8.4			5.0	0.81	14	3,000	4.5	0.62				
24 June	104	201	0	3		4.1	28	---	----	1	200		0.46	0	Db	Ka^{2}Kb	Wd
			1	27	9.0			---	----	10	1,750	7.8	0.62				
			10	41	13.7			---	----	15	2,000	8.9	0.68				
2 July	105	237	0	2		3.4	25	---	----	1	60		0.49	0	Db	Ka^{3}Kb	Wd
			1	33	16.5			---	----	11	1,500	7.8	0.62				
			10	48	24.0			---	----	18	1,500	8.3	0.66				
Sno-Cat 743, Weight 8,230 lb																	
16 May	106	36	0	22		1.3	27	2.6	0.12	24	300		0.34	-5	Db	Kc^{6}Kd	Wa
			1	13	0.6			3.3	0.13	30	200	0.6	0.37				
			10	19	0.9			3.6	0.12	34	850	2.7	0.41				
23 May	107	79	0	18		1.8	24	3.2	0.19	18	1,750		0.39	-4	Db	Kc^{2}Kd	Wa
			1	17	0.9			3.1	0.22	24	1,500	0.2	0.43				
			10	21	1.2			3.6	0.24	15	1,400	0.2	0.44				
30 May	108	102	0	14		2.4	22	2.0	0.16	9	450		0.36	-6	Db	Kc	Wa
			1	15	1.1			2.4	0.20	15	1,100	0.3	0.40				
			10	19	1.4			2.5	0.24	13	1,100	1.9	0.43				
5 June	109	109	0	6		3.3	20	1.0	0.12	3	-----		0.22	-5	Db	Ka^{4}Kb	Wa
			1	12	2.0			2.4	0.13	9	-----	1.0	0.31				
			10	17	2.8			2.7	0.17	21	-----	2.4	0.39				
10 June	110	126	0	13		2.8	24	1.5	0.13	10	500		0.37	-2	Db	Kc	Wc
			1	17	1.3			1.8	0.16	18	1,250	0.5	0.42				
			10	24	1.8			2.1	0.20	34	550	1.2	0.36				
20 June	111	169	0	5		4.4	50	1.2	0.20	3	200		0.50	0	Db	Ka^{1}Kd^{5}Kc	Wd
			1	16	3.2			3.4	0.55	10	800	2.4	0.64				
			10	29	5.8			5.8	0.78	13	2,500	3.0	0.61				
24 June	112	199	0	3		3.9	31	---	----	1	100		0.49	0	Db	Ka^{1}Kb	Wd
			1	24	8.0			---	----	12	2,150	4.9	0.60				
			10	45	15.0			---	----	17	4,500	5.0	0.63				
2 July	113	233	0	2		4.4	39	---	----	1	120		0.49	0	Db	Ka^{1}Kb	Wd
			1	32	16.0			---	----	14	5,000	6.2	0.65				
			10	56	28.0			---	----	10	4,500	7.4	0.60				
Otter M76, Weight 9,960 lb																	
4 May	114	4	0	11		2.3	17	4.3	0.22	--	-----		0.32	-17	Db	Kd^{1}Kc^{5}Kd	Wa
			1	28	2.5			3.7	0.35	--	-----	3.0	0.44				
			10	38	3.5			4.2	0.52	--	-----	5.4	0.47				
8 May	115	10	0	8		3.1	14	2.7	0.13	---	-----		0.32	-18	Db	Ka^{2}Kc^{4}Kd	Wa
			1	16	2.0			3.5	0.20	--	-----	2.4	0.38				
			10	23	2.9			3.1	0.23	--	-----	3.9	0.48				
18 May	116	43	0	14		2.0	16	2.1	0.12	12	330		0.35	-5	Db	Kb^{4}Kd	Wc^{4}Wa
			1	30	2.1			3.3	0.12	28	550	2.4	0.46				
			10	27	1.9			3.4	0.30	21	350	4.6	0.46				
21 May	117	70	0	21		1.5	32	3.5	0.17	12	1,100		0.38	-6	Db	Kb^{2}Kd^{4}Kc	Wa
			1	30	1.4			3.7	0.22	19	2,000	1.7	0.43				
			10	42	2.0			2.8	0.23	10	1,650	4.2	0.49				
27 May	118	94	0	19		2.0	27	2.5	0.12	25	350		0.36	-4	Db	Kc	Wa
			1	21	1.1			2.8	0.14	17	1,250	1.3	0.39				
			10	16	0.8			2.2	0.19	13	2,250	3.8	0.49				
5 June	119	118	0	11		3.8	32	1.1	0.12	4	200		0.29	-4	Db	Ka	Wa
			1	25	2.3			3.2	0.25	15	600	3.2	0.43				
			10	39	3.5			2.6	0.40	23	900	5.5	0.43				
11 June	120	133	0	11		2.4	28	1.3	0.17	10	250		0.32	-1	Db	Kc	Wc^{5}Wa
			1	56	5.1			4.0	0.62	48	6,000	3.2	0.46				
			10	69	6.3			3.9	0.56	75	8,000	5.6	0.48				
20 June	121	174	0	6		4.0	48	1.3	0.31	3	150		0.44	0	Db	Ka^{3}Kc	Wd
			1	54	9.0			6.7	1.02	2	2,500	7.8	0.66				
			10	83	13.8			9.7+		34	5,500	8.5	0.67				
24 June	122	200	0	3		3.8	31	---	----	1	100		0.49	0	Db	Ka^{1}Kb	Wd
			1	52	17.3			---	----	20	4,500	10.2	0.68				
			10	75	25.0			---	----	26	20,000	10.2	0.70				
2 July	123	234	0	2		3.6	19	---	----	1	120		0.49	0	Db	Ka^{1}Kb	Wd
			1	51	25.5			---	----	13	2,500	11.5	0.65				
			10	82	41.0			---	----	20	3,500	11.9	0.64				

* Number designates the depth in inches at which a change in snow property occurred.

Table 8

Summary of Results of Self-Propelled, Tracked Vehicle (Weighing More Than 10,000 lb) Tests, 1957

Average Before- and After-Traffic Data

Date	Item No.	Field Test No.	Pass No.	Strength Measurements 0- to 12-in. Depth: Cone Index	Vehicle Compaction Strength Index	50-blow: Compaction in.	50-blow: Rating Cone Index	Vane Shear Strength psi: Initial	Vane Shear Strength psi: Residual	Ramm Hardness No.	Canadian Hardness g/cm^2	Rut Depth in.	Snow Measurements 0- to 12-in. Depth: Density g/cm^3	Temp °C	Snow Classification: Grain Nature	Hardness	Wetness
Standard D6 Tractor (30-in. Track Width), Weight 18,340 lb																	
3 May	124	1	0	23		1.5	30	3.7	0.14	--	-----		0.36	-22	Db	Kd^1Kb^6Kc*	Wa
			1	31	1.3			3.7	0.18	--	-----	2.4	0.40				
			10	57	2.5			4.7	0.68	--	-----	4.0	0.44				
3 May	125	2	0	19		3.2	33	1.8	0.13	--	-----		0.32	-21	Db	Kc^1Kd^3Kb	Wa
			1	36	1.9			3.2	0.30	--	-----	4.0	0.42				
			10	53	2.8			3.5	0.35	--	-----	5.7	0.45				
4 May	126	3	0	15		2.4	27	1.9	0.10	--	-----		0.32	-18	Db	$Kd^1Kc^5Kd^6Kb$	Wa
			1	31	2.1			3.0	0.28	--	-----	4.2	0.41				
			10	57	3.8			3.7	0.50	--	-----	6.2	0.48				
7 May	127	8	0	23		1.4	20	4.7	0.35	--	-----		0.31	-12	Db	Ka^1Kc^4Kd	Wa
			1	32	1.4			4.1	0.53	--	-----	3.0	0.37				
			10	87	3.8			6.1	0.66	--	-----	5.7	0.44				
9 May	128	12	0	10		2.8	20	2.3	0.12	--	-----		0.34	-14	Db	$Kd^2Kc^4Kd^6Kc^{11}Kb$	Wa
			1	24	2.4			2.5	0.29	--	-----	4.2	0.37				
			10	78	7.8			3.7	0.36	--	-----	7.9	0.45				
18 May	129	45	0	13		3.4	34	2.3	0.12	21	525		0.35	-6	Db	Kb^4Kc^9Kd	Wc^4Wa*
			1	35	2.8			2.7	0.17	40	1,500	4.5	0.43				
			10	53	4.1			3.8	0.41	46	2,000	9.0	0.48				
21 May	130	68	0	22		1.6	34	3.0	0.12	26	2,065		0.38	-9	Db	Kd^1Kc^6Kd	Wa
			1	32	1.5			[illegible].8	0.14	32	1,750	2.8	0.44				
			10	59	2.7			4.1	0.31	49	2,125	5.9	0.49				
29 May	131	98	0	14		2.3	25	2.2	0.12	20	1,100		0.35	-7	Db	Kc^6Kd	Wa
			1	29	2.1			2.2	0.14	25	1,250	3.2	0.41				
			10	50	3.6			2.3	0.24	35	1,500	5.9	0.50				
1 June	132	106	0	15		3.1	34	1.8	0.13	17	465		0.34	-6	Db	Kb^2Kc^6Kd	Wa
			1	30	2.0			2.3	0.22	29	1,250	3.8	0.45				
7 June	133	115	0	10		3.8	22	1.8	0.14	15	1,125		0.34	-7	Db	Kc^6Kd	Wa
			1	31	3.1			3.4	0.28	33	1,625	4.9	0.44				
			10	65	6.5			5.7	0.36	47	1,050	9.0	0.45				
13 June	134	144	0	11		3.8	75	1.2	0.14	7	300		0.39	0	Db	Kc	Wc
			1	55	5.0			5.5+	0.48	49	9,500	4.6	0.61				
			10	103	9.4			6.8+	0.77	77	13,375	7.4	0.61				
21 June	135	179	0	6		4.1	61	1.0	0.19	2	200		0.46	0	Db	Kb^3Kc	Wd
			1	65	10.8			8.2+	1.47	39	725	9.4	0.64				
			10	119	19.9					52	22,500	10.8	0.58				
Hi-speed Tractor M5A4, Weight 25,440 lb																	
13 May	136	19	0	12		---	--	2.3	0.14	--	-----		0.35	-10	Db	$Kb^3Kd^7Kc^9Kd^{11}Kc$	Wa
			1	48	4.0	---	--	3.7	0.34	--	-----	8.2	0.47				
			10	97	8.1	---	--	5.3	0.98	--	-----	13.8	0.53				
15 May	137	27	0	12		---	--	2.0	0.16	--	-----		0.32	-6	Db	Kb^3Kd^9Kc	Wc^3Wa
			1	35	2.9	---	--	2.6	0.35	--	-----	10.1	0.48				
			10	48	4.0	---	--	4.2	0.60	--	-----	16.2	0.54				
21 May	138	71	0	10		---	--	2.2	0.13	--	-----		0.37	-7	Db	$Kb^2Kd^4Kc^6Kd^8Kc^{10}Kd$	Wa
			1	42	4.2	---	--	2.3	0.31	--	-----	8.8	0.46				
			10	61	6.1	---	--	3.7	0.42	--	-----	13.9	0.47				
27 May	139	93	0	12		---	--	2.3	0.12	--	-----		0.36	-4	Db	Kc^6Kd	Wa
			1	34	2.8	---	--	2.2	0.22	--	-----	8.0	0.46				
			10	45	3.8	---	--	2.9	0.46	--	-----	13.8	0.50				
5 June	140	110	0	9		---	--	1.6	0.13	--	-----		0.29	-6	Db	$Ka^4Kb^6Kc^{10}Kd$	Wa
			1	35	3.9	---	--	2.1	0.29	--	-----	9.9	0.48				
			10	68	7.6	---	--	2.7	0.86	--	-----	15.7	0.52				
12 June	141	138	0	14		---	--	1.9	0.30	--	-----		0.39	0	Db	Ka^1Kc	Wc^6Wa
			1	89	6.4	---	--	6.4	0.70	--	-----	6.6	0.50				
			10	160	11.4	---	--	6.7	1.20	--	-----	11.2	0.55				
20 June	142	171	0	7		---	--	1.4	0.29	--	-----		0.46	0	Db	Ka^1Kd^4Kc	Wd
			1	84	12.0	---	--	7.9	0.88	--	-----	12.8	0.67				
			10	320	45.7	---	--			--	-----	15.1	0.68				
24 June	143	202	0	3		---	--	---	----	--	-----		0.48	0	Db	Ka^2Kb	Wd
			1	86	29.3	---	--	---	----	--	-----	19.5	0.69				
			10	332	110.7	---	--	---	----	--	-----	19.6	0.72				
3 July	144	241	0	4		---	--	---	----	--	-----		0.49	0	Db	Ka^7Kb	Wd
			1	84	21.0	---	--	---	----	--	-----	15.5	0.62				
Hi-speed Tractor M4, Weight 31,400 lb																	
6 May	145	6	0	14		---	--	2.8	0.36	--	-----		0.36	-14	Db	Kb^3Kd^9Kb	Wa
			1	39	2.8	---	--	4.1	0.76	--	-----	7.8	0.48				
			10	89	6.4	---	--	6.7	0.55	--	-----	14.4	0.54				
8 May	146	9	0	16		---	--	2.5	0.12	--	-----		0.35	-15	Db	$Ka^2Kd^3Kc^4Kd^8Kb$	Wa
			1	32	2.0	---	--	3.0	0.27	--	-----	9.5	0.45				
			10	103	6.4	---	--	4.7	0.70	--	-----	14.8	0.54				
11 May	147	13	0	12		---	--	2.9	0.14	--	-----		0.34	-10	Db	$Ka^2Kd^3Kb^7Kc$	Wa
			1	40	3.3	---	--	3.2	0.51	--	-----	8.4	0.48				
			10	105	8.8	---	--	5.2	0.82	--	-----	14.6	0.54				
18 May	148	47	0	14		---	--	3.0	0.14	--	-----		0.37	-6	Db	Kb^6Kd	Wa
			1	46	3.3	---	--	3.3	0.31	--	-----	9.2	0.49				
			10	102	7.3	---	--	3.9	0.53	--	-----	15.0	0.51				

(Continued)

* Number designates the depth in inches at which a change in snow property occurred.

Table 8 (Concluded)

Date	Item No.	Field Test No.	Pass No.	Cone Index	Strength Measurements, 0- to 12-in. Depth: Vehicle Compaction Strength Index	50-blow Compaction in.	Rating Cone Index	Vane Shear Strength psi: Initial	Vane Shear Strength psi: Residual	Ram Hardness No.	Canadian Hardness g/cm^2	Rut Depth in.	Snow Measurements, 0- to 12-in. Depth: Density g/cm^3	Temp °C	Snow Classification: Grain Nature	Snow Classification: Hardness	Snow Classification: Wetness
Hi-speed Tractor M4, Weight 31,400 lb (Continued)																	
29 May	149	100	0	13		---	--	2.5	0.13	--	-----		0.33	-6	Db	Kc^{3}Kd	Wa
			1	27	2.1	---	--	2.0	0.27	--	-----	9.8	0.46				
			10	71	5.5	---	--	3.6	1.14	--	-----	16.2	0.54				
1 June	150	107	0	17		---	--	2.3	0.14	--	-----		0.34	-6	Db	Kb^{2}Kc^{6}Kd	Wa
			1	46	2.7	---	--	2.3	0.30	--	-----	8.2	0.52				
5 June	151	111	0	9		---	--	[illegible]	0.14	--	-----		0.28	-4	Db	Ka^{4}Kb^{8}Kc	Wa
			1	32	3.6	---	--	[illegible]	0.27	--	-----	11.2	0.45				
			10	91	10.1	---	--	[illegible]	1.97	--	-----	18.4	0.50				
12 June	152	140	0	13		---	--	2.2	0.36	--	-----		0.40	0	Db	Ka^{1}Kc	Wc^{6}Wa
			1	97	7.5	---	--	7.7+	0.50	--	-----	9.0	0.54				
			10	197	15.2	---	--	5.4	0.70	--	-----	13.8	0.64				
17 June	153	160	0	15		---	--	2.0	0.35	--	-----		0.44	0	Db	Kd^{3}Kc	Wd
			1	94	6.3	---	--	8.0	1.50	--	-----	12.9	0.58				
			10	320	21.3	---	--	---	----	--	-----	14.2	0.64				
21 June	154	176	0	6		---	--	1.2	0.27	--	-----		0.44	0	Db	Kb^{6}Kc	Wd
			1	87	14.5	---	--	7.4	0.89	--	-----	17.8	0.56				
27 June	155	205	0	2		---	--	---	----	--	-----		0.46	0	Db	Kc^{4}Kb	Wd
			1	83	41.5	---	--	---	----	--	-----	21.7	0.71				
			10	289	144.5	---	--	---	----	--	-----	21.6					
4 July	156	246	0	3		---	--	---	----	--	-----		0.52	0	Db	Ka^{8}Kc	Wd
			1	88	29.3	---	--	---	----	--	-----	20.3	0.62				
			10	312	104.0	---	--	---	----	--	-----	20.6	0.68				
LGP-D8 Tractor, Weight 66,000 lb																	
15 May	157	30	0	15		---	--	2.8	0.17	--	-----		0.33	-6	Db	Kc^{3}Kd^{4}Kb	Wa
			1	30	2.0	---	--	3.3	0.24	--	-----	3.2	0.48				
			10	67	4.5	---	--	5.5	0.67	--	-----	7.4	0.46				
23 May	158	77	0	24		---	--	2.1	0.12	--	-----		0.38	-7	Db	Kc^{3}Kd	Wa
			1	29	1.2	---	--	2.3	0.17	--	-----	3.0	0.43				
			10	65	2.7	---	--	3.3	0.52	--	-----	6.4	0.47				
21 June	159	178	0	8		---	--	1.1	0.22	--	-----		0.47	0	Db	Kb^{6}Kc	Wd
			1	54	6.8	---	--	4.2	1.20	--	-----	7.6	0.62				
			10	115	14.4	---	--			--	-----	10.4	0.72				
28 June	[illegible]	207	0	6		---	--	---	----	--	-----		0.47	0	Db	Ka^{1}Kc^{3}Kb	Wd
			1	61	10.2	---	--	---	----	--	-----	10.1	0.64				
			10	115	19.2	---	--	---	----	--	-----	11.8	0.66				
3 July	161	243	0	5		---	--	---	----	--	-----		0.49	0	Db	Ka^{8}Kb	Wd
			1	68	13.6	---	--	---	----	--	-----	10.6	0.68				
			10	103	20.6	---	--	---	----	--	-----	11.6	0.68				
Medium Tank M48, Weight 96,430 lb																	
13 May	162	18	0	13		---	--	3.2	0.19	--	-----		0.35	-10	Db	Kb^{3}Kd^{7}Kc^{9}Kd^{11}Kc	Wa
			1	55	4.2	---	--	4.3	0.58	--	-----	11.2	0.50				
			10	103	7.9	---	--	5.4	0.93	--	-----	17.3	0.54				
16 May	163	31	0	16		---	--	2.7	0.14	--	-----		0.27	-6	Db	Kb^{7}Kc^{9}Kd^{10}Kb	Wa
			1	46	2.9	---	--	3.9	0.55	--	-----	11.4	0.51				
			10	112	7.0	---	--	5.3	0.80	--	-----	17.6	0.54				
22 May	164	73	0	13		---	--	2.2	0.16	--	-----		0.34	-9	Db	Kd^{1}Kc	Wa
			1	51	3.9	---	--	3.4	0.82	--	-----	12.0	0.50				
			10	110	8.5	---	--	3.9	0.89	--	-----	17.8	0.59				
2[illegible] May	165	96	0	17		---	--	2.4	0.12	--	-----		0.36	-7	Db	Kc^{6}Kd	Wa
			1	44	2.6	---	--	2.4	0.55	--	-----	10.1	0.49				
			10	130	7.6	---	--	4.1	1.01	--	-----	14.4	0.54				
1 June	166	109	0	15		---	--	2.3	0.14	--	-----		0.34	-6	Db	Kb^{2}Kc^{6}Kd	Wa
			1	58	3.9	---	--	2.3	0.95	--	-----	11.9	0.46				
7 June	167	116	0	13		---	--	2.2	0.12	--	-----		0.31	-5	Db	Kc^{6}Kd	Wa
			1	60	4.6	---	--	4.6	0.36	--	-----	13.0	0.48				
			10	107	8.2	---	--	6.1	[illegible]	--	-----	18.8	0.54				
13 June	168	142	0	8		---	--	1.8	0.31	--	-----		0.39	0	Db	Kc	Wc
			1	113	14.9	---	--	7.1	1.18	--	-----	13.0	0.57				
			10	190	23.8	---	--	7.6	1.28	--	-----	16.8	[illegible]				
21 June	169	177	0	7		---	--	1.3	0.30	--	-----		0.42	0	Db	Kb^{6}Kc	Wd
			1	135	19.3	---	--	9.8+		--	-----	16.2	0.69				
27 June	170	209	0	4		---	--	---	----	--	-----		0.46	0	Db	Ka^{1}Kc^{5}Kb	Wd
			1	144	36.0	---	--	---	----	--	-----	18.8	0.64				
			10	[illegible]	99.0	---	--	---	----	--	-----	19.2	0.66				
3 July	171	[illegible]	0	2		---	--	---	----	--	-----		0.49	0	Db	Ka^{4}Kb	Wd
			1	132	66.0	---	--	---	----	--	-----	18.9	0.67				
			10	419	209.5	---	--	---	----	--	-----	[illegible]	0.69				

Table 9

Summary Evaluation of Snow-Property Measurements, Self-Propelled Tracked Vehicle Tests

Rut-Depth Correlations

	Average Before-Traffic Snow Measurements										
				Vane Shear Strength				2-1/4-in. Torque Tube Shear Strength			
	Cone Index	Compaction in Remolding Cylinder	Rating Cone Index	Initial	Residual	Ram Hardness	Canadian Hardness	Initial	Residual	Drop-Cone Hardness	Density
Vehicles Weighing Less Than 10,000 lb											
Weasel M29C											
Dry and moist snow											
Number of readings	16	16	16	16	16	13	13	3	3	4	16
Rut depth range, in.	5.0	5.0	5.0	5.0	5.0	4.9	4.9	1.5	1.5	4.3	5.0
Average deviation, in.	0.38	0.30	1.91	0.40	0.52	0.52	1.04	0.50	0.50	0.35	0.33
Per cent error	17.4	20.5	73.4	19.5	27.1	26.8	60.8	18.5	22.3	16.4	52.8
Wet snow											
Number of readings	6	6	6	4	4	6	6	3	3	3	-----
Rut depth range, in.	6.4	6.4	6.4	2.4	2.4	6.4	6.4	0.6	0.6	0.6	-----
Average deviation, in.	0.50	2.07	0.48	0.55	1.28	0.22	1.02	0.13	0.03	0.16	-----
Per cent error	14.2	35.2	23.1	21.8	31.3	9.6	23.2	7.9	2.2	9.7	-----
Sno-Cat 743											
Dry and moist snow											
Number of readings	8	8	8	8	8	8	7	2	3	3	8
Rut depth range, in.	3.4	3.4	3.4	3.4	3.4	3.4	3.4	0.2	2.6	2.6	3.4
Average deviation, in.	0.30	0.26	0.82	0.55	0.46	0.18	0.16	0	0.6	0	0.21
Per cent error	38.0	39.1	72.0	54.6	40.5	37.3	12.5	0	33.7	0	17.7
Wet snow											
Number of readings	5	5	5	3	3	5	5	1	1	2	-----
Rut depth range, in.	4.8	4.8	4.8	1.0	1.0	4.8	4.8	0	0	0.3	-----
Average deviation, in.	0.12	1.40	1.92	0.80	1.13	0.52	0.54	0	0	0.30	-----
Per cent error	5.7	34.5	50.4	42.3	141.8	20.4	15.4	0	0	13.1	-----
Otter M76											
Dry and moist snow											
Number of readings	12	11	12	12	12	10	10	4	4	4	12
Rut depth range, in.	7.1	3.0	7.1	7.1	7.1	7.1	7.1	5.0	5.0	6.4	7.1
Average deviation, in.	0.38	0.54	1.68	0.49	1.00	0.47	0.86	1.32	1.2	0.05	0.56
Per cent error	14.5	24.8	61.0	24.5	35.7	20.1	27.4	24.4	27.3	1.1	42.7
Wet snow											
Number of readings	6	6	6	4	4	6	6	3	3	3	-----
Rut depth range, in.	8.9	8.9	8.9	5.2	5.2	8.9	8.9	1.2	1.2	1.2	-----
Average deviation, in.	0.25	1.13	0.05	1.28	1.72	0.70	0.70	0.90	0.63	0.37	-----
Per cent error	6.1	16.0	0.4	34.0	33.0	12.6	12.3	28.2	14.1	13.1	-----
All Vehicles Weighing Less Than 10,000 lb and All Snow Classes											
Average deviation, in.	0.34	0.75	1.32	0.56	0.84	0.44	0.77	0.62	0.59	0.20	0.38
Per cent error	17.1	26.8	54.2	29.6	39.8	22.6	30.7	16.3	19.3	8.7	41.6
Vehicles Weighing More Than 10,000 lb											
Standard D6 Tractor											
Dry and moist snow											
Number of readings	18	18	13	18	18	13	13	7	7	5	18
Rut depth range, in.	5.8	5.8	5.8	5.8	5.8	5.4	5.4	5.2	5.2	5.2	5.8
Average deviation, in.	0.52	0.34	2.09	0.43	0.93	0.80	1.17	1.05	0.97	0.70	0.82
Per cent error	10.2	7.9	34.1	10.6	18.2	16.8	22.1	20.0	18.7	12.0	21.5
Wet snow											
Number of readings	8	8	8	8	8	8	8	-----	-----	4	-----
Rut depth range, in.	5.6	5.6	5.6	5.6	5.6	5.6	5.6	-----	-----	1.4	-----
Average deviation, in.	1.39	1.74	2.25	1.36	4.35	1.74	1.49	-----	-----	0.88	-----
Per cent error	16.6	40.2	26.6	18.9	39.8	20.1	18.1	-----	-----	13.3	-----
Hi-speed Tractor M5A4											
Dry and moist snow											
Number of readings	6	-----	-----	6	6	-----	-----	-----	-----	-----	6
Rut depth range, in.	3.5	-----	-----	3.5	3.5	-----	-----	-----	-----	-----	3.5
Average deviation, in.	0.58	-----	-----	0.90	0.80	-----	-----	-----	-----	-----	0.57
Per cent error	7.7	-----	-----	9.4	10.5	-----	-----	-----	-----	-----	6.7
Wet snow											
Number of readings	3	-----	-----	1	1	-----	-----	-----	-----	-----	-----
Rut depth range, in.	6.7	-----	-----	0	0	-----	-----	-----	-----	-----	-----
Average deviation, in.	0.70	-----	-----	0	2.2	-----	-----	-----	-----	-----	-----
Per cent error	4.0	-----	-----	0	14.7	-----	-----	-----	-----	-----	-----
LGP-D7 Tractor											
Dry and moist snow											
Number of readings	6	6	6	6	6	6	6	6	6	4	6
Rut depth range, in.	4.1	4.1	4.1	4.1	4.1	4.1	4.1	4.1	4.1	2.6	4.1
Average deviation, in.	0.55	0.72	1.05	0.55	1.02	0.87	0.75	1.05	0.95	0.93	0.55
Per cent error	12.4	17.3	39.1	11.6	23.0	24.5	13.8	30.7	30.7	29.8	14.7
Wet snow											
Number of readings	3	3	3	3	3	3	3	3	3	3	-----
Rut depth range, in.	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	-----
Average deviation, in.	1.53	0.77	0.80	0.67	0.77	1.83	1.10	0.90	0.70	0.83	-----
Per cent error	35.6	13.7	12.6	11.9	18.8	47.4	17.3	14.4	10.3	12.7	-----

(Continued)

Table 9 (Concluded)

	Average Before-Traffic Snow Measurements										
	Cone Index	Compaction in Remolding Cylinder	Rating Cone Index	Vane Shear Strength Initial	Vane Shear Strength Residual	Ram Hardness	Canadian Hardness	2-1/4-in. Torque Tube Shear Strength Initial	2-1/4-in. Torque Tube Shear Strength Residual	Drop-Cone Hardness	Density
Vehicles Weighing More Than 10,000 lb (Continued)											
Hi-speed Tractor M4											
Dry and moist snow											
Number of readings	8	-----	-----	8	8	-----	-----	-----	-----	-----	8
Rut depth range, in.	3.4	-----	-----	3.4	3.4	-----	-----	-----	-----	-----	3.4
Average deviation, in.	0.96	-----	-----	0.90	1.50	-----	-----	-----	-----	-----	1.02
Per cent error	10.1	-----	-----	9.2	20.1	-----	-----	-----	-----	-----	11.3
Wet snow											
Number of readings	4	-----	-----	2	2	-----	-----	-----	-----	-----	-----
Rut depth range, in.	8.8	-----	-----	4.9	4.9	-----	-----	-----	-----	-----	-----
Average deviation, in.	0	-----	-----	0	1.85	-----	-----	-----	-----	-----	-----
Per cent error	0	-----	-----	0	12.4	-----	-----	-----	-----	-----	-----
LGP-D8 Tractor											
Dry and moist snow											
Number of readings	2	-----	-----	2	2	-----	-----	-----	-----	-----	2
Rut depth range, in.	0.2	-----	-----	0.2	0.2	-----	-----	-----	-----	-----	0.2
Average deviation, in.	0.55	-----	-----	0.45	0.67	-----	-----	-----	-----	-----	0.75
Per cent error	14.6	-----	-----	11.6	23.4	-----	-----	-----	-----	-----	18.6
Wet snow											
Number of readings	3	-----	-----	1	1	-----	-----	-----	-----	-----	-----
Rut depth range, in.	3.0	-----	-----	0	0	-----	-----	-----	-----	-----	-----
Average deviation, in.	0.37	-----	-----	0	2.90	-----	-----	-----	-----	-----	-----
Per cent error	4.1	-----	-----	0	27.6	-----	-----	-----	-----	-----	-----
Medium Tank M48											
Dry and moist snow											
Number of readings	7	-----	-----	7	7	-----	-----	-----	-----	-----	7
Rut depth range, in.	2.9	-----	-----	2.9	2.9	-----	-----	-----	-----	-----	2.9
Average deviation, in.	0.88	-----	-----	0.63	1.28	-----	-----	-----	-----	-----	1.33
Per cent error	6.7	-----	-----	5.0	12.7	-----	-----	-----	-----	-----	10.7
Wet snow											
Number of readings	3	-----	-----	1	1	-----	-----	-----	-----	-----	-----
Rut depth range, in.	2.7	-----	-----	0	0	-----	-----	-----	-----	-----	-----
Average deviation, in.	0.57	-----	-----	1.30	0.40	-----	-----	-----	-----	-----	-----
Per cent error	3.1	-----	-----	7.3	2.4	-----	-----	-----	-----	-----	-----
All Vehicles Weighing More Than 10,000 lb and All Snow Classes											
Average deviation, in.	0.73	0.76	1.84	0.68	1.53	1.17	1.16	1.02	0.92	0.84	0.86
Per cent error	10.3	17.4	31.4	10.2	20.1	22.3	18.9	22.8	21.4	16.9	15.3
All Vehicles and Snow Classes											
Number of readings	124	87	88	110	110	78	77	32	33	35	83
Average deviation, in.	0.56	0.76	1.53	0.63	1.23	0.72	0.92	0.83	0.75	0.49	0.65
Per cent error	13.2	23.0	45.1	18.5	28.5	22.5	26.0	19.6	20.3	12.4	26.7

Table 10

Summary of Stress Pattern Test Results for Self-Propelled Tracked Vehicle Tests

Before- and After-Traffic Data

Wetness	Rut Depth in.	Depth to Bottom of Stress Bulb from Virgin Snow Surface, in.	Stress Bulb Thickness in.	(Stress Bulb Thickness, in. / Depth to Bottom of Stress Bulb, in.) X 100	Average Cone Index			Density, g/cm³		
					Before Traffic	1 Pass in Stress Bulb	Vehicle Compaction Index 1 Pass/0 Pass	Before Traffic	1 Pass in Stress Bulb	Index 1 Pass/0 Pass
Weasel M29C, Ground-Contact Pressure 1.68 psi										
Dry*	1.0	6.0	5.0	83	13	17	1.31	0.33	0.37	1.14
Dry	0.5	4.0	3.5	87	19	--	----	----	----	----
Moist*	1.5	7.0	5.5	79	10	--	----	----	----	----
Wet*	7.0	28.0	21.0	75	4	--	----	----	----	----
Hi-speed Tractor M5A4, Ground-Contact Pressure 6.37 psi										
Dry*	7.5	19.0	11.5	61	10	41	4.10	0.34	0.48	1.41
Moist*	11.0	24.5	14.5	55	8	--	----	----	----	----
Wet*	16.0	40.0	24.0	60	4	--	----	----	----	----
LGP-D8 Tractor, Ground-Contact Pressure 3.59 psi										
Dry*	5.0	22.0	17.0	77	11	26	2.36	0.35	0.44	1.25
Moist*	9.0	33.0	24.0	73	--	--	----	----	----	----
Wet*	11.0	40.0	29.0	72	--	--	----	----	----	----
Medium Tank M48, Ground-Contact Pressure 10.50 psi										
Dry*	12.0	28.0	16.0	57	16	75	4.69	0.34	0.55	1.57
Dry	14.5	32.0	17.5	55	11	--	----	----	----	----
Moist	10.5	31.0	20.5	66	11	--	----	----	----	----
Moist*	13.0	32.5	19.5	60	9	--	----	----	----	----
Wet*	16.0	45.0	29.0	64	5	--	----	----	----	----

* Photographs of these stress patterns are shown in plate 26, sheets 1-6.

Table 11

Self-Propelled Tracked Vehicle Tests, Remolding Data

No. of Tests	Snow Wetness	Cone Index			Compaction Strength Index		Remolding Index*	Rating Cone Index
		0 Pass	1 Pass	10 Passes	1 Pass	10 Passes		
Vehicles Weighing Less Than 10,000 lb, 0- to 6-in. Depth								
Weasel M29C								
12	Dry	8	13	18	1.9	3.1	3.70	21
4	Moist	12	25	35	2.2	3.1	3.26	27
6	Wet	9	25	39	6.0	9.1	7.85	50
Sno-Cat 743								
7	Dry	11	12	17	1.4	2.2	3.22	23
1	Moist	13	17	24	1.3	1.8	1.85	24
5	Wet	5	25	45	6.9	12.5	9.90	38
Otter M76								
9	Dry	10	20	29	3.7	5.0	3.23	23
3	Moist	14	46	53	3.5	4.0	2.86	41
6	Wet	32	54	76	10.2	15.6	6.16	78
Vehicles Weighing More Than 10,000 lb, 0- to 12-in. Depth								
Standard D6 Tractor								
16	Dry	13	30	60	3.0	5.7	3.12	32
2	Moist	18	57	99	3.8	7.2	4.90	74
8	Wet	20	63	119	7.2	9.0	6.98	121
Hi-speed Tractor M5A4								
5	Dry	11	38	64	3.6	5.9	----	---
1	Moist	14	89	160	6.4	11.4	----	---
3	Wet	5	85	326	20.8	78.2	----	---
LGP-D7 Tractor								
4	Dry	9	28	62	3.9	9.8	5.34	[illegible]
2	Moist	26	74	108	2.8	4.2	8.95	[illegible]
3	Wet	45	68	148	2.0	4.4	[illegible]	[illegible]
Hi-speed Tractor M4								
7	Dry	14	37	94	2.8	7.4	----	---
1	Moist	13	97	197	7.5	[illegible]	----	---
4	Wet	6	88	307	22.9	[illegible]	----	---
LGP-D8 Tractor								
2	Dry	20	30	66	1.6	3.6	----	---
3	Wet	6	61	111	10.2	18.1	----	---
Medium Tank M48								
6	Dry	14	52	112	3.7	6.5	----	---
1	Moist	8	119	190	14.9	23.8	----	---
3	Wet	5	137	408	40.4	154.2	----	---

* 25-blow compaction was used for vehicles weighing less than 10,000 lb and 50 blows for vehicles weighing more than 10,000 lb.

Table 12

Summary of Results of Self-Propelled, Wheeled Vehicle Tests, 1955

Average Before- and After-Traffic Data at 0- to 12-in. Depth

Item No.	Field Test No.	Pass No.	Cone Index	Strength Measurements, 0- to 12-in. Depth: 50 Blow Compaction in Remolding Cyl in.	Rating Cone Index	Vane Shear Strength, psi Initial	Vane Shear Strength, psi Residual	Ram Hardness No.	Canadian Hardness g/cm²	Drop-Cone Hardness g/cm³	Rut Depth in.	Snow Measurements, 0- to 12-in. Depth: Density g/cm³	Temp °C	Snow Classification: Nature	Hardness	Wetness	Tire Pressure psi	Load lb	Remarks
									2-1/2-ton Truck M47, Weight 13,540 lb										
49	7-3	0	12	4.1	92	1.1	0.32	5	825	---		0.41	-0.2	Fa^{3}Dd*	Kb^{6}Kc*	Wd	10	0	Vehicle had difficulty making first pass
		1	110			10.6**	----	31	17,500	---	14.0	0.63							
		10	179			11.8**	----	62	15,000	---	13.6	0.59							Ten passes completed but snow condition considered to be critical
50	7-4	0	17	3.8	161	1.4	0.38	6	3,540	15		0.48	-0.1	Fa^{3}Dd	Kd	Wd	10	0	Immobilized on first pass
		1	95			10.6**	1.18	33	33,160	154	15.7	0.60							
		10	---			----	----	--	----	---	----	----							
51	7-10	0	50	2.8	120	5.4	0.41	25	2,800	32		0.42	-0.2	Db^{4}Dd	Kb^{4}Ke^{7}Kc	Wd	10	0	Immobilized on first pass
		1	106			12.3**	----	35	21,670	242	13.5	0.61							
		10	---			----	----	--	----	---	----	----							
52	60-5	0	29	2.8	168	2.6	0.26	19	1,000	---		0.41	-0.2	Db	Kb	Wc	40	1000	Immobilized on first pass because of high tire pressure
		1	106			8.4**	----	75	43,670	---	8.6	0.54							
		10	---			----	----	--	----	---	----	----							
53	60-6	0	34	2.8	184	1.5	0.14	14	1,000	---		0.43	-0.2	Db	Kb	Wc	10	1000	Completed 10 passes with ease
		1	82			8.2**	----	64	21,670	---	9.0	0.49							
		10	---			----	----	--	----	---	----	----							
54	60-7	0	23	2.8	124	1.9	0.22	9	1,000	---		0.43	-0.2	Db	Kb	Wc	10	5200	Completed 10 passes with ease
		1	101			7.3**	0.24	70	35,000	---	9.2	0.49							
		10	135			9.1**	0.82	56	23,460	---	9.7	0.54							
									Rolligon Terracruiser XM357, Weight 29,500 lb										
55	31-7	0	10	4.8	48	1.6	0.05	12	350	---		0.32	-13.0	Db	Kb^{3}Kc	Wa	3-5	5000	Completed 2 passes with ease
		1	19			2.6	0.32	13	1,100	---		0.38							
		2	36			3.4	0.44	18	5,000	---		0.43							
56	31-8	0	10	4.1	20	1.4	0.07	6	10,600	---		0.32	-12.0	Fa^{3}Db	Ka^{3}Kc^{4}Kb^{6}Kd	Wa	3-5	0	Completed first pass. Immobilized in turning at end of lane
		1	29			3.3	0.32	21	4,300	---		0.42							
57	31-9	0	11	4.2	25	----	----	5	----	---		0.32	-13.0	Db	Kb^{6}Kc	Wa	3-5	0	Completed 2 passes with ease
		1	27			----	----	32	----	---		0.40							
		2	29			----	----	35	----	---		0.34							
									Tournadozer, Weight 36,000 lb										
58	7-9	0	40	1.7	88	4.1	0.53	29	1,380	---	----	0.41	-0.2	Db^{4}Dd^{9}Db	Kb^{4}Kc	Wd	5	0	Immobilized on first pass
		1	145			13.8**	----	74	31,700	---	11.6	0.58							
		10	---					--		---	----	----							

* Number designates the depth in inches at which a change in snow property occurred.
** Several of the readings used in the average were maximum instrument readings.

Table 13

Summary of Results of Lightweight Tracked Vehicle Towing Tests, 1955

Average Before-, During-, and After-Traffic Data

Strength Measurements

Item No.	Field Test No.	Pass No.	Cone Index	0- to 12-in. Depth: After 25 Blows: Compaction in.	After 25 Blows: Rating Cone Index	Vane Shear Strength, psi: Initial	Vane Shear Strength, psi: Residual	Ram Hardness No.	Canadian Hardness g/cm²	Torque Tube Shear Strength, psi: 2-1/4-in. Tube: Moved: Initial	2-1/4-in. Moved: Residual	2-1/4-in. Not Moved: Initial	2-1/4-in. Not Moved: Residual	5-in. Tube: Moved: Initial	5-in. Moved: Residual	5-in. Not Moved: Initial	5-in. Not Moved: Residual	Drop-Cone Hardness, g/cm³	Rut Depth in.
Weasel M29C, Weight 5450 lb																			
59	7-14A	0	10	2.9	60	0.7	0.03	4	510	3.4	1.7	5.3	2.2	6.9	1.8	4.4	1.2	9	
		1	22			4.5	0.50	22	1,370									17	4.4
60	7-14C	0	9	3.1	78	1.8	0.34	4	430	5.9	1.7	5.6	2.3	6.9	1.9	4.5	1.8	9	
		1	33			4.8	0.53	15	960									17	3.2
61	7-15E	0	8	2.8	51	1.0	0.11	8	190	4.9	1.9	5.1	1.8	6.4	1.8	5.0	1.6	14	
		1	31			4.5	0.88	24	2,190									28	5.0
62	7-15F	0	8	3.1	62	1.2	0.14	4	390	5.5	2.0	4.1	1.7	6.4	1.7	4.9	1.6	14	
		1	31			3.2	0.34	15	2,110									28	3.5
63	32-10	0	11	2.1	42	1.0	0.03	14	2,600	5.4	2.1	5.4	1.5	---	---	---	---	80	
		1	21			3.3	0.24	9	2,[illegible]40									26	4.2
64	70-4	0	25	4.0	29	2.0	0.05	12	410	2.0	1.2	2.0	1.2	---	---	---	---	9	
		1	16			2.2	0.12	14	1,670									--	3.4
65**	70-5	0	32	1.4	45	3.3	0.27	46	3,[illegible]	3.6	1.2	3.1	1.0	---	---	---	---	9	
		1	25			2.2	0.26	25	[illegible]									--	1.0
66	122-7	0	8	4.1	50	0.9	0.05	5	140	2.6	1.1	3.0	1.3	---	---	---	---	36	
		1	17			1.4	0.20	13	1,090									--	3.4
67	150-5	0	8	4.9	40	0.7	0.03	2	[illegible]	2.8	1.2	3.4	1.2	---	---	---	---	18	
		1	14			1.4	0.10	11	1,[illegible]									18	4.4
68	220-5	0	5	4.9	44	0.6	0.07	3	350	5.3	1.9	7.2	2.2	---	---	---	---	--	
		1	14			1.6	0.17	10	710									--	5.1
69	220-14	0	2	6.1†	15	0.2	0	2	560	3.0	2.1	2.3	2.0	---	---	---	---	3	
		1	11			2.2	0.0[illegible]	15	1,030									32	6.7
70	220-15	0	3	6.1†	23	0.2	0.02	1	590	3.0	1.9	2.2	2.4	---	---	---	---	--	
		1	11			1.4	0.10	10	2,920									--	7.6
Otter M76, Weight 9950 lb																			
71	32-6	0	20	2.4	46	2.0	0.10	26	3,000	5.2	1.9	5.9	2.8	---	---	---	---	123	
		1	15			2.4	0.07	6	1,720									--	5.6
72	70-10	0	14	4.2	38	1.9	0.00	10	2,400	3.0	1.3	2.6	1.2	---	---	---	---	33	
		1	13			1.8	0.03	20	1,760									--	4.2
73	150-10	0	7	3.6	25	0.8	0.02	6	510	2.3	1.3	3.8	1.7	---	---	---	---	23	
		1	14			1.8	0.02	12	1,620									--	5.2
74	270-19	0	5	5.6†	22	0.4	0.02	4	320	1.7	1.3	---	0.7	---	---	---	---	3	
		1	16			2.2	0.16	10	1,250									--	7.6

Snow Measurements and Towing Test Data

Item No.	Pass No.	Snow Measurements, 0- to 12-in. Depth: Density g/cm³	Temp °C	Snow Classification: Grain Nature	Snow Classification: Hardness	Snow Classification: Wetness	Towing Test Data: Data Run: Drawbar Pull lb	Max Towing Force: Drawbar Pull lb	Max Towing Force: Slip %	Max Towing Force: Tractive Coefficient	Towed Test Data: Towing Force lb	Towed Test Data: % Vehicle Weight	Towed Test Data: Rut Depth in.
Weasel M29C, Weight 5450 lb													
59	0	0.49	-0.5	Dd^2Db^6Dd*	Kb	Wd							
	1	0.57					750	1,950	11	0.36			
60	0	0.49		Dd	Kb^8Kc*	Wd							
	1	0.57					1,700	1,700	25	0.31			
61	0	0.47	0.0	Dd	Kb	Wd							
	1	0.58					1,750	1,800	36	0.33			
62	0	0.47		$Dd^{10}Dc$	$Kb^6Kc^{10}Kb$	Wd							
	1	0.57					1,100	1,900	55	0.35			
63	0	0.51	-1.0	Dd	Kc^5Kb	Wc							
	1	0.57					1,750	2,000	24	0.37	450	8.3	0.0
64	0	0.32	-6.2	Fa^3Db	Kb	Wa							
	1	0.40					2,050	2,200	23	0.40	600	11.0	1.5
65**	0	0.44	-7.9	Fa^3Db	Kd^3Kc^9Kd	Wa							
	1	0.46					2,250	2,300	22	0.43	550	10.1	0.0
66	0	0.33	-6.5	[illegible]	Kb	Wc^3Wa*							
	1	0.39					1,750	2,000	26	0.37			
67	0	0.29	-10.5	Db	Kb	Wa							
	1	0.40					1,950	1,950	23	0.36	600	11.0	3.0
68	0	0.31	-9.0	Db	Kb	Wa							
	1	0.38					1,600	1,700	20	0.31			
69	0	0.29	-8.4	Fa^4Db	Ka^4Kb	Wa							
	1	0.39					1,650	1,700	18	0.31	750	13.8	5.6
70	0	0.26	-8.4	Fa^4Db	Ka^4Kb	Wa							
	1	0.38					1,400	1,400	17	0.26			
Otter M76, Weight 9950 lb													
71	0	0.49	-0.1	Dd	Kc	Wd							
	1	0.53					3,600	3,600	74	0.50	1,380	13.9	3.7
72	0	0.31	-7.9	$Fa^2Db^{10}Dd$	Kd^4Kb	Wa							
	1	0.38					3,500	3,700	55	0.37	1,700	17.1	3.0
73	0	0.30	-11.2	Db	Kb^9Kc	Wa							
	1	0.40					2,450	2,700	35	0.27	1,900	19.1	4.0
74	0	0.26	-9.9	Fa^4Db	Kb	Wa							
	1	0.40					2,500	2,600	44	0.26			

* Number designates the depth in inches at which a change in snow property occurred.
** Age-hardened lane.
† Data from compaction characteristic curves.

Table 14

Summary of Results of Tracked Vehicle (Weighing More Than 10,000 lb) Towing Tests, 1955

Average Before-, During-, and After-Traffic Data

Item No.	Field Test No.	Pass No.	Strength Measurements, 0- to 12-in. Depth: Cone Index	After 50 Blows: Compaction in.	After 50 Blows: Rating Cone Index	Vane Shear Strength psi: Initial	Vane Shear Strength psi: Residual	Ramm Hardness No.	Canadian Hardness g/cm²	Torque Tube Shear Strength psi, 2-1/4-in. Tube, Moved: Initial	Moved: Residual	Not Moved: Initial	Not Moved: Residual	Drop-Cone Hardness g/cm³	Rut Depth in.	Snow Measurements, 0- to 12-in. Depth: Density g/cm³	Temp °C	Snow Classification: Grain Nature	Snow Classification: Hardness	Wetness	Towing Test Data: Data Run Drawbar Pull lb	Max Towing Force: Drawbar Pull lb	Max Towing Force: Slip %	Max Towing Force: Tractive Coefficient	Towed Test Data: Towing Force lb	Towed Test Data: % Vehicle Weight	Towed Test Data: Rut Depth in.
															Standard D6 Tractor, Weight 18,340 lb												
75	32-3	0	39	2.6	78	2.6	0.14	23	3,670	---	---	---	---	30		0.47	-1.0	Db^{2}Dd*	Kb^{2}Kd^{9}Kc*	Wc							
		1	44			5.6	0.31	30	6,500					--	5.9	0.59					7,000	7,600	12	0.41	4,300	21.2	6.2
76	70-7	0	9	4.9	34	1.5	0.03	11	1,300	5.5	5.6	6.2	2.5	33		0.26	-7.7	Fa^{1}Db	Ka^{1}Kb	Wa							
		1	21			3.1	0.14	24	1,660					--	6.8	0.43					6,600	7,000	8	0.38	2,000	10.9	5.0
77**	70-8	0	42	1.4	55	3.6	0.24	47	4,500	7.3	2.0	5.9	2.0	33		0.47	-9.5	Db	Kc^{3}Kc	Wa							
		1	25			3.6	0.36	64	2,660					--	1.5	0.45					10,400	11,000	23	0.60	2,400	7.6	0.0
78	150-7	0	7	4.8	63	0.7	0.02	4	500	4.1	2.1	6.7	2.5	25		0.34	-10.6	Db	Kb	Wa							
		1	24			1.8	0.27	12	2,380					--	7.9	0.44					4,500	4,900	16	0.27	2,650	14.4	6.6
79	220-15	0	3	6.5†	40	0.1	0.00	3	370	5.0	2.8	4.2	2.6	3		0.26	-10.0	Fa^{4}Db	Ka^{4}Kb	Wa							
		1	24			2.3	0.30	13	2,580					28	9.4	0.46					4,400	4,800	11	0.26			
80	220-17	0	3	6.2	33	0.5	0.03	5	370	5.0	2.7	4.2	2.4	3		0.26	-10.0	Fa^{4}Db	Ka^{4}Kb	Wa							
		1	22			2.3	0.20	15	1,250	---	---	---	---	28	8.6	0.43					4,000	4,000	5	0.22			
															LGP-D7 Tractor, Weight 26,200 lb												
81	220-4	0	4	5.4	23	1.1	0.07	7	780	5.3	2.5	6.7	3.0	14		0.30	-7.5	Db	Kb	Wa							
		1	35					15	1,380					35	10.3	0.46					10,000	10,000	24	0.38			

* Number designates the depth in inches at which a change in snow property occurred.
** Age-hardened lane.
† Data from compaction characteristic curves.

Table 15

Summary of Results of Lightweight Tracked Vehicle Towing Tests, 1957

Average Before- and After-Traffic Data

				Strength Measurements, 0- to 12-in. Depth								Snow Measurements, 0- to 12-in. Depth					Towing Test Data						
					After 25 Blows									Snow Classification			Data Run	Max Towing Force			Towed Test Data		
Date	Item No.	Field Test No.	Pass No.	Cone Index	Compaction in.	Rating Cone Index	Vane Shear Strength, psi Initial	Vane Shear Strength, psi Residual	Ram Hardness No.	Canadian Hardness g/cm²	Rut Depth in.	Density g/cm³	Temp °C	Grain Nature	Hardness	Wetness	Drawbar Pull lb	Drawbar Pull lb	Slip %	Tractive Coefficient	Towing Force lb	% Vehicle Weight	Rut Depth in.
											Weasel M29C, Weight 5450 lb												
14 May	172	24	0	10	3.2	18	2.0	0.12	12	420		0.32	-5	Db	$Kb^{4}Kc^{8}Kb$*	Wa							
			1	15			2.0	0.12	17	640	1.8	0.38					2300	2300	15	0.42	680	12.5	0.0
18 May	173	42	0	10	1.9	28	2.9	0.13	22	490		0.35	-7	Db	$Kb^{4}Kd^{7}Kc^{9}Kd$	$Wc^{4}Wa$*							
			1	--			---	----	--	---	---	----					2200	2300		0.42			
			10	21			2.7	0.10	--	19,500	---	0.42											
			11															2430		0.44			
21 May	174	72	0	21	2.7	46	2.2	0.12	18	1,370		0.37	-7	Db	$Kb^{2}Kd^{4}Kc^{6}Kd^{8}Kc^{10}Kd$	Wa							
			1	18			2.2	0.13	28	830	1.8	0.39					2100	2600	21	0.48	710	13.0	0.2
29 May	175	101	0	15	2.8	32	2.5	0.12	20	450		0.33	-6	Db	$Kc^{3}Kd$	Wa							
			1	16			2.4	0.17	23	780	2.0	0.42					2240	2560	32	0.47	600	11.0	0.5
5 June	176	112	0	12	3.6	27	1.5	0.12	10	---		0.26	-4	Db	$Ka^{4}Kb^{8}Kc$	Wa							
			1	18			2.0	0.17	21	---	3.2	0.40					1600	2240	17	0.41	650	11.9	0.7
11 June	177	136	0	11	3.6	54	1.3	0.19	13	330		0.36	-3	Db	Kc	$Wc^{5}Wa$							
			1	23			2.2	0.35	32	3,630	3.2	0.46					2300	2330		0.43			
			10	27			2.8	0.25	--	---	---	0.49											
			11															2450		0.45			
13 June	178	143	0	12	3.3	60	1.3	0.23	3	300		0.39	0	Db	Kc	Wc							
			1	32			4.1	0.39	34	7,630	4.0	0.49					2300	2800	20	0.51	470	8.6	1.3
17 June	179	167	0	11	3.5	44	---	----	5	350		0.43	0	Db	Kc	Wc							
			1	37			---	----	18	780	4.1	0.49					2800	2900	22	0.53	650	11.9	---
20 June	180	172	0	7	4.1	62	1.2	0.24	3	330		0.46	0	Db	$Ka^{1}Kd^{6}Kc$	$Wd^{1}Wc$							
			1	31			3.9	0.67	16	580	4.5	0.62					2100	2100		0.39			
28 June	181	210	0	4	3.7	18	---	----	2	300		0.52	0	Db	$Kb^{1}Kc^{4}Kb$	Wc							
			1	38			---	----	8	3,500	9.6	0.62					1200	1800	16	0.33	1,225	22.5	9.2
2 July	182	238	0	3	---	--	---	----	1	120		0.49	0	Db	$Ka^{3}Kb$	Wd							
			1	40			---	----	12	1,050	7.2	0.60					1700	1750		0.32			
4 July	183	245	0	3	---	--	---	----	1	290		0.52	0	Db	$Ka^{8}Kc$	Wd							
			1	37			---	----	15	530	8.4	0.59					1500	1750	17	0.32	1,050	19.3	---
											Otter M76, Weight 9960 lb												
16 May	184	33	0	20	---	--	2.7	0.17	25	730		0.39	-5	Db	$Kb^{1}Kd^{2}Kc^{8}Kd$	Wa							
			1	25			2.8	0.22	33	780	3.4	0.45					3200	3200	45	0.32	2,870	28.8	3.0
18 May	185	44	0	16	2.0	18	2.5	0.12	21	490		0.35	-7	Db	$Kb^{4}Kd^{7}Kc^{9}Kd$	$Wc^{4}Wa$							
			1	--			---	----	--	---	---	----					3200	3400		0.34			
			10	24			2.8	0.25	--	500		0.42											
			11															5470		0.55			

(Continued)

* Number designates the depth in inches at which a change in snow property occurred.

Table 15 (Concluded)

Date	Item No.	Field Test No.	Pass No.	Cone Index	Strength Measurements, 0- to 12-in. Depth: After 25 Blows: Compaction in.	After 25 Blows: Rating Cone Index	Vane Shear Strength, psi: Initial	Vane Shear Strength, psi: Residual	Ram Hardness No.	Canadian Hardness g/cm²	Rut Depth in.	Snow Measurements, 0- to 12-in. Depth: Density g/cm³	Temp °C	Snow Classification: Grain Nature	Snow Classification: Hardness	Snow Classification: Wetness	Towing Test Data: Data Run: Drawbar Pull lb	Max Towing Force: Drawbar Pull lb	Max Towing Force: Slip %	Tractive Coefficient	Towed Test Data: Towing Force lb	Towed Test Data: % Vehicle Weight	Towed Test Data: Rut Depth in.
Otter M76, Weight 9960 lb (Continued)																							
22 May	186	74	0 1	16 25	2.4	29	2.3 2.3	0.16 0.22	23 23	1,400 1,430	3.0	0.36 0.42	-7	Db	Kc^4Kd	Wa	1700	3200	63	0.32	2,050	20.6	3.5
30 May	187	103	0 1	16 21	2.2	35	2.4 2.3	0.17 0.17	14 27	850 350	1.2	0.38 0.42	-6	Db	Kc^6Kd	Wa	3120	3120	30	0.31	1,760	17.7	4.3
5 June	188	113	0 1	10 19	3.2	26	1.6 2.1	0.14 0.18	14 26	--- ---	3.8	0.26 0.41	-4	Db	Ka^4Kb^3Kc	Wa	2400	2850	58	0.28	1,670	16.8	3.5
11 June	189	134	0 1 10 11	12 25 48	3.4	45	1.1 1.5 2.7	0.12 0.27 0.40	12 34 --	250 5,500 ---	4.7 ---	0.35 0.46 0.49	-2	Db	Kc	Wc^4Wa	3680	3880 4460		0.33 0.45			
14 June	190	158	0 1	10 37	4.0	70	1.8 4.4	0.36 0.44	7 19	670 1,600	3.0	0.43 0.48	0	Db	Ka^2Kd^3Kc	Wc	2000	4640	33	0.46	1,360	13.7	5.0
24 June	191	203	0 1	3 48	3.9	38	--- ---	---- ----	2 5	200 2,500	9.8	0.48 0.64	0	Db	Ka^2Kb	Wd	1600	2550	18	0.26	2,130	21.4	---
2 July	192	236	0 1	2 25	---	--	--- ---	---- ----	-- --	120 500	9.8	0.49 0.64	0	Db	Ka^3Kb	Wd	2000	2000		0.20			
4 July	193	248	0 1	3 51	3.6	50	--- ---	---- ----	1 22	290 1,250	9.1	0.52 0.61	0	Db	Ka^6Kc	Wd	2300	2300	25	0.23	2,100	21.0	---

Table 16

Summary of Results of Tracked Vehicle (Weighing More Than 10,000 lb) Towing Tests, 1957

Average Before-, During-, and After-Traffic Data

Date	Item No.	Field Test No.	Pass No.	Cone Index	Strength Measurements, 0- to 12-in. Depth: After 50 Blows: Compaction in.	After 50 Blows: Rating Cone Index	Vane Shear Strength, psi: Initial	Vane Shear Strength, psi: Residual	Ramm Hardness No.	Canadian Hardness g/cm²	Rut Depth in.	Snow Measurements, 0- to 12-in. Depth: Density g/cm³	Temp °C	Snow Classification: Grain Nature	Snow Classification: Hardness	Snow Classification: Wetness	Towing Test Data: Data Run: Drawbar Pull lb	Max Towing Force: Drawbar Pull lb	Max Towing Force: Slip %	Max Towing Force: Tractive Coefficient	Towed Test Data: Towing Force lb	Towed Test Data: % Vehicle Weight	Towed Test Data: Rut Depth in.
Standard D6 Tractor, Weight 18,340 lb																							
17 May	194	37	0	10	3.0	18	1.3	0.12	5	180		0.30	-5	Db	Kb^5Kc*	Wa							
			1	34			2.0	0.19	24	2,950	4.5	0.47					7,000	7,200	28	0.39			
18 May	195	46	0	13	3.4	34	2.3	0.12	21	525		0.35	-6	Db	Kb^4Kc^9Kd	Wc^4Wa*							
			1	--			---	----	--	---	---	----											
			10	53			3.8	0.41	46	2,000	---	0.48					7,800	7,900		0.42			
			11																				
23 May	196	78	0	26	2.3	72	2.2	0.17	17	250		0.38	-7	Db	Kc^3Kd	Wa		10,500		0.57			
			1	46			2.9	0.38	31	1,050	3.8	0.42					6,800	8,600	23	0.47	2,730	9.4	3.2
30 May	197	104	0	20	2.4	30	3.2	0.17	16	1,530		0.40	-6	Db	$Kd^8Kc^{10}Kd$	Wa							
			1	32			2.4	0.30	32	1,050	4.0	0.43					6,000	7,600	24	0.42	2,130	11.6	4.2
13 June	198	145	0	10	4.4	119	1.3	0.19	8	430		0.44	0	Db	$Ka^3Kc^9Kd^{10}Kc$	Wc							
			1	49			4.3	0.64	61	3,380	6.2	0.56					8,800	11,200		0.61			
			10	103			6.8	0.77	77	13,375		0.61											
			11															12,600		0.69			
20 June	199	175	0	6	3.8	44	1.1	0.27	2	200		0.46	0	Db	Ka^3Kc	Wc							
			1	77			8.4	1.30	45	3,000	8.6	0.64					8,800	10,000	10	0.55	3,100	16.9	---
Hi-speed Tractor M5A4, Weight 25,440 lb																							
21 May	200	69	0	19	---	--	3.4	0.14	--	---		0.37	-9	Db	Kd^4Kc^6Kd	Wa							
			1	42			2.4	0.32	--	---	8.6	0.48					6,600	7,600	61	0.30	6,130	24.0	6.7
31 May	201	105	0	14	---	--	2.4	0.18	--	---		0.40	-7	Db	Kd	Wa							
			1	27			1.8	0.42	--	---	9.2	0.46					5,400	6,400	38	0.25	5,550	21.8	8.6
7 June	202	117	0	13	---	--	1.7	0.12	--	---		0.31	-5	Db	Kc^6Kd	Wc^3Wa							
			1	36			4.3	0.27	--	---	10.0	0.50					6,000	6,300	28	0.25	4,670	18.4	2.5
11 June	203	137	0	13	---	--	1.5	0.24	--	---		0.36	0	Db	Kc	Wc^3Wa							
			1	41			2.1	0.50	--	---	11.4	0.56					8,600	8,800	45	0.35	3,800	14.9	7.2
20 June	204	173	0	6	---	--	1.2	0.24	--	---		0.46	0	Db	Ka^3Kc	Wc							
			1	86			8.0+	0.80	--	---	14.2	0.64					7,000	7,500		0.29			
27 June	205	204	0	4	---	--	---	----	--	---		0.46	0	Db	Kc^4Kb	Wd							
			1	79			---	----	--	---	19.3	0.69					6,400	6,800	10	0.27	5,400	21.0	26.2
2 July	206	235	0	2	---	--	---	----	--	---		0.48	0	Db	Ka^1Kb	Wd							
			1	74			---	----	--	---	17.4	0.67					6,200	6,600	15	0.26	5,700	22.4	---
5 July	207	249	0	3	---	--	---	----	--	---		0.49	0	Db	Ka^3Kb^9Kc	Wd							
			1	79			---	----	--	---	17.8	0.63					6,800	7,100		0.28			
Hi-speed Tractor M4, Weight 31,400 lb																							
18 May	208	48	0	18	---	--	3.0	0.14	--	---		0.37	-6	Db	Kb^6Kd	Wa							
			1	--			---	----	--	---	----	----											
			10	102			3.9	0.53	--	---		0.51					12,400	11,150		0.36			
			11															12,270		0.39			
28 May	209	97	0	14	---	--	2.1	0.12	--	---		0.36	-7	Db	Kc^6Kd	Wa							
			1	43			2.1	0.30	--	---	10.8	0.52					7,600	7,600	25	0.24	7,670	24.4	9.5
7 June	210	119	0	13	---	--	2.2	0.13	--	---		0.32	-4	Db	Ka^6Kb	Wc^3Wa							
			1	28			2.7	0.32	--	---	8.0	0.47					8,800	9,600	51	0.31	6,600	21.0	6.5

(Continued)

* Number designates the depth in inches at which a change in snow property occurred.

Table 16 (Concluded)

Date	Item No.	Field Test No.	Pass No.	Cone Index	Strength Measurements, 0- to 12-in. Depth: After 50 Blows: Compaction in.	After 50 Blows: Rating Cone Index	Vane Shear Strength, psi: Initial	Vane Shear Strength, psi: Residual	Ram Hardness No.	Canadian Hardness g/cm^2	Rut Depth in.	Snow Measurements, 0- to 12-in. Depth: Density g/cm^3	Temp °C	Snow Classification: Grain Nature	Snow Classification: Hardness	Snow Classification: Wetness	Towing Test Data: Data Run: Drawbar Pull lb	Max Towing Force: Drawbar Pull lb	Max Towing Force: Slip %	Max Towing Force: Tractive Coefficient	Towed Test Data: Towing Force lb	Towed Test Data: % Vehicle Weight	Towed Test Data: Rut Depth in.
Hi-speed Tractor M4, Weight 31,400 lb (Continued)																							
12 June	211	141	0	8	---	--	1.4	0.19	--	---		0.40	0	Db	Ka^{1}Kc	Wc							
			1	52			4.2	0.59	--	---	10.6	0.54					12,800	12,800		0.41			
			11															14,900		0.48			
15 June	212	159	0	5	---	--	1.2	0.28	--	---		0.40	0	Db	Ka^{6}Kc	Wc							
			1	79			8.8+	1.52	--	---	12.2	0.56					12,000	12,400	38	0.40	6,400	20.4	13.5
21 June	213	180	0	5	---	--	---	----	--	---		0.46	0	Db	Kb^{3}Kc	Wc							
			1	89			---	----	--	---	12.8	0.64					10,000	12,800	22	0.41	7,600	24.2	---
27 June	214	206	0	3	---	--	---	----	--	---		0.46	0	Db	Kb	Wd							
			1	81			---	----	--	---	20.2	0.65					12,000	12,200		0.39			
29 June	215	212	0	4	---	--	---	----	--	---		0.49	0	Db	Kb	Wd							
			1	96			---	----	--	---	20.0	0.66					10,600	11,600	5	0.37	7,200	22.9	---
3 July	216	240	0	3	---	--	---	----	--	---		0.49	0	Db	Ka^{3}Kb	Wd							
			1	91			---	----	--	---	16.3	0.65					4,600	11,600	12	0.37	7,100	22.6	---
4 July	217	247	0	2	---	--	---	----	--	---		0.52	0	Db	Ka^{8}Kc	Wd							
			1	72			---	----	--	---	18.8	0.66					10,800	10,500		0.33			
LGP-D8 Tractor, Weight 66,000 lb																							
19 May	218	49	0	16	---	--	2.2	0.12	--	---		0.36	-6	Db	Kb^{1}Kc^{9}Kd	Wc^{3}Wa							
			1	32			2.5	0.14	--	---	4.8	0.43					25,000	28,000	29	0.42			
24 May	219	84	0	16	---	--	2.5	0.14	--	---		0.39	-8	Db	Kc^{6}Kd	Wa							
			1	31			3.1	0.31	--	---	3.4	0.44					20,000	25,000		0.38	6,330	9.6	3.2
18 June	220	168	0	6	---	--	---	----	--	---		0.51	0	Db	Kd^{6}Kb	Wc							
			1	77			---	----	--	---	11.4	0.60					20,000	33,500	17	0.51	7,300	11.1	---
28 June	221	208	0	5	---	--	---	----	--	---		0.47	0	Db	Ka^{1}Kc^{3}Kb	Wd							
			1	76			---	----	--	---	12.9	0.66					26,000	34,500		0.52	7,330	11.1	---
3 July	222	244	0	3	---	--	---	----	--	---		0.49	0	Db	Ka^{8}Kb	Wd							
			1	74			---	----	--	---	10.2	0.67					31,000	33,000		0.50	7,400	11.2	---
Medium Tank M48, Weight 96,430 lb																							
16 May	223	32	0	16	---	--	2.7	0.14	--	---		0.37	-6	Db	Kb^{7}Kc^{9}Kd^{10}Kb	Wa							
			1	--			---	----	--	---	----	----					27,000	27,300		0.28			
22 May	224	76	0	12	---	--	1.5	0.12	--	---		0.34	-6	Db	Kc^{6}Kd	Wa							
			1	76			3.8	0.82	--	---	13.4	0.52					22,000	22,500		0.23	16,170	16.8	---
29 May	225	99	0	14	---	--	2.4	0.12	--	---		0.35	-7	Db	Kc^{6}Kd	Wa							
			1	89			3.2	0.77	--	---	12.4	0.53					14,000	18,000	49	0.19	11,000	11.1	5.3
12 June	226	139	0	8	---	--	1.2	0.18	--	---		0.39	0	Db	Ka^{1}Kc	Wc^{6}Wa							
			1	61			3.3	0.72	--	---	10.4	0.54					20,000	23,000	18	0.26	10,000	10.1	9.3
17 June	227	161	0	11	---	--	---	----	--	---		0.44	0	Db	Kd^{3}Kc^{10}Kd	Wc							
			1	101			---	----	--	---	12.8	0.56					31,000	35,000	17	0.36	13,250	13.3	15.0
28 June	228	211	0	4	---	--	---	----	--	---		0.52	0	Db	Kb^{1}Kc^{4}Kb	Wd							
			1	154			---	----	--	---	19.2	0.67					24,000	24,000		0.25			
29 June	229	213	0	4	---	--	---	----	--	---		0.49	0	Db	Kb	Wd							
			1	146			---	----	--	---	18.0	0.64					21,000	22,000	10	0.23			
3 July	230	242	0	3	---	--	---	----	--	---		0.49	0	Db	Ka^{8}Kb	Wd							
			1	152			---	----	--	---	15.6	0.67					29,000	29,000		0.30			
5 July	231	250	0	2	---	--	---	----	--	---		0.49	0	Db	Ka^{3}Kb^{9}Kc	Wd							
			1	132			---	----	--	---	16.5	0.65					11,000	23,000	5	0.25			

Table 17

Summary Evaluation of Snow-Property Measurements, Tracked Vehicle Towing Tests

Tractive Coefficient Correlations

	Average Before-Traffic Snow Measurements									
	Cone Index	Compaction in Remolding Cylinder	Rating Cone Index	Vane Shear Strength Initial	Ramm Hardness No.	Canadian Hardness	2-1/4-in. Torque Tube Shear Strength Initial	2-1/4-in. Torque Tube Shear Strength Residual	Drop-Cone Hardness	Density
Vehicles Weighing Less Than 10,000 lb										
Weasel M29C										
Dry snow										
Number of readings	12	12	12	12	12	11	6	6	4	12
Tractive coefficient range	0.22	0.22	0.22	0.22	0.22	0.22	0.14	0.14	0.09	0.22
Average deviation	0.016	0.021	0.052	0.023	0.018	0.062	0.033	0.013	0.038	0.038
Per cent error	4.6	5.6	13.0	6.2	4.6	17.5	14.6	3.8	11.6	11.3
Moist snow										
Number of readings	5	5	5	3	5	5	---	---	---	5
Tractive coefficient range	0.20	0.20	0.20	0.14	0.20	0.20	---	---	---	0.20
Average deviation	0.040	0.050	0.054	0.030	0.108	0.062	---	---	---	0.030
Per cent error	8.4	10.6	10.6	7.1	19.4	13.5	---	---	---	7.2
Wet snow										
Number of readings	6	4	4	4	6	6	4	4	4	6
Tractive coefficient range	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Average deviation	0.033	0.018	0.015	0.008	0.077	0.023	0.018	0.025	0.030	0.038
Per cent error	12.2	5.1	4.3	2.2	31.5	6.9	5.1	7.2	9.0	15.4
Otter M76										
Dry snow										
Number of readings	9	8	8	9	9	8	2	3	3	9
Tractive coefficient range	0.13	0.12	0.12	0.13	0.13	0.13	0.10	0.11	0.11	0.13
Average deviation	0.030	0.039	0.025	0.033	0.028	0.041	0.080	0.073	0.047	0.029
Per cent error	9.5	15.8	9.9	10.8	8.7	14.7	25.2	21.5	19.3	10.4
Wet snow										
Number of readings	4	3	3	---	3	4	---	---	---	4
Tractive coefficient range	0.16	0.13	0.13	---	0.13	0.16	---	---	---	0.16
Average deviation	0.010	0.027	0.063	---	0.0	0.012	---	---	---	0.052
Per cent error	3.9	9.7	15.9	---	0.0	5.1	---	---	---	19.9
All Vehicles Weighing Less Than 10,000 lb and All Snow Classes										
Number of readings	36	32	32	28	35	34	12	13	11	36
Average deviation	0.025	0.030	0.042	0.025	0.042	0.044	0.035	0.031	0.037	0.037
Per cent error	7.5	9.3	11.0	7.2	12.0	12.9	13.2	8.9	12.7	12.2
Vehicles Weighing More Than 10,000 lb										
Standard D6 Tractor										
Dry snow										
Number of readings	8	8	8	8	8	8	4	4	4	8
Tractive coefficient range	0.25	0.25	0.25	0.25	0.25	0.25	0.16	0.16	0.16	0.25
Average deviation	0.021	0.032	0.104	0.032	0.036	0.082	0.042	0.065	0.030	0.053
Per cent error	5.5	9.3	31.6	15.7	10.8	26.8	12.5	17.7	9.5	17.3
Moist snow										
Number of readings	3	3	3	3	3	3	---	---	---	3
Tractive coefficient range	0.20	0.20	0.20	0.20	0.20	0.20	---	---	---	0.20
Average deviation	0.0	0.0	0.103	0.0	0.030	0.007	---	---	---	0.050
Per cent error	0.0	0.0	24.3	0.0	5.1	1.3	---	---	---	9.3
Hi-speed Tractor M5A4										
Dry snow										
Number of readings	4	---	---	4	---	---	---	---	---	4
Tractive coefficient range	0.10	---	---	0.10	---	---	---	---	---	0.10
Average deviation	0.040	---	---	0.078	---	---	---	---	---	0.015
Per cent error	7.6	---	---	41.7	---	---	---	---	---	5.0
Wet snow										
Number of readings	3	---	---	---	---	---	---	---	---	3
Tractive coefficient range	0.02	---	---	---	---	---	---	---	---	0.02
Average deviation	0.013	---	---	---	---	---	---	---	---	0.027
Per cent error	4.8	---	---	---	---	---	---	---	---	10.6

(Continued)

Table 17 (Concluded)

	Average Before-Traffic Snow Measurements									
	Cone Index	Compaction in Remolding Cylinder	Rating Cone Index	Vane Shear Strength Initial	Ram Hardness No.	Canadian Hardness	2-1/4-in. Torque Tube Shear Strength Initial	2-1/4-in. Torque Tube Shear Strength Residual	Drop-Cone Hardness	Density
Vehicles Weighing More Than 10,000 lb (Cont'd)										
Hi-speed Tractor M4										
Dry snow										
Number of readings	3	---	---	3	---	---	---	---	---	3
Tractive coefficient range	0.12	---	---	0.12	---	---	---	---	---	0.12
Average deviation	0.037	---	---	0.027	---	---	---	---	---	0.053
Per cent error	12.3	---	---	9.0	---	---	---	---	---	18.6
Moist snow										
Number of readings	3	---	---	2	---	---	---	---	---	3
Tractive coefficient range	0.01	---	---	0.01	---	---	---	---	---	0.01
Average deviation	0.033	---	---	0.025	---	---	---	---	---	0.040
Per cent error	8.6	---	---	6.4	---	---	---	---	---	9.3
Wet snow										
Number of readings	4	---	---	---	---	---	---	---	---	4
Tractive coefficient range	0.06	---	---	---	---	---	---	---	---	0.06
Average deviation	0.012	---	---	---	---	---	---	---	---	0.007
Per cent error	3.6	---	---	---	---	---	---	---	---	2.0
LGP-D8 Tractor										
Dry snow										
Number of readings	2	---	---	2	---	---	---	---	---	2
Tractive coefficient range	0.02	---	---	0.04	---	---	---	---	---	0.04
Average deviation	0	---	---	0.035	---	---	---	---	---	0.035
Per cent error	0	---	---	8.9	---	---	---	---	---	7.9
Wet snow										
Number of readings	2	---	---	---	---	---	---	---	---	2.0
Tractive coefficient range	0.0	---	---	---	---	---	---	---	---	0.0
Average deviation	0.025	---	---	---	---	---	---	---	---	0.010
Per cent error	4.2	---	---	---	---	---	---	---	---	1.8
Medium Tank M48										
Dry snow										
Number of readings	4	---	---	4	---	---	---	---	---	4
Tractive coefficient range	0.09	---	---	0.09	---	---	---	---	---	0.09
Average deviation	0.032	---	---	0.065	---	---	---	---	---	0.030
Per cent error	15.2	---	---	35.6	---	---	---	---	---	12.4
Wet snow										
Number of readings	4	---	---	---	---	---	---	---	---	---
Tractive coefficient range	0.07	---	---	---	---	---	---	---	---	---
Average deviation	0.042	---	---	---	---	---	---	---	---	---
Per cent error	15.9	---	---	---	---	---	---	---	---	---
All Vehicles Weighing More Than 10,000 lb and All Snow Classes										
Number of readings	40	11	11	26	11	11	4	4	4	36
Average deviation	0.024	0.025	0.104	0.039	0.035	0.062	0.042	0.065	0.030	0.034
Per cent error	7.3	6.8	31.9	18.9	9.2	19.3	6.1	17.7	12.5	10.5
All Vehicles and Snow Classes										
Number of readings	76	43	43	54	46	45	17	17	15	72
Average deviation	0.024	0.028	0.058	0.032	0.040	0.048	0.038	0.037	0.035	0.036
Per cent error	7.4	8.6	16.4	12.9	11.3	14.5	11.4	11.0	11.8	11.4

Table 18

Summary of Results of Towed Vehicle Tests, 1955, Average Before- and After-Traffic Data

Item No.	Field Test No.	Pass No.	Strength Measurements, 0- to 6-in. Depth: Cone Index	25 Blow: Compaction in.	25 Blow: Rating Cone Index	Vane Shear Strength, psi: Initial	Vane Shear Strength, psi: Residual	Ram Hardness No.	Canadian Hardness g/cm^2	Torque Tube Shear Strength, psi, 2-1/4-in. Tube, Moved: Initial	Moved: Residual	Not Moved: Initial	Not Moved: Residual	Drop-Cone Hardness g/cm^3	Rut Depth in.	Snow Measurements, 0- to 6-in. Depth: Density g/cm^3	Temp °C	Snow Classification: Grain Nature	Hardness	Wetness	Towed Test Data, Avg: Maximum Static Pull lb	Maximum Static Coefficient Friction	Kinetic Pull lb	Kinetic Coefficient Friction
Sled, Compacted Snow, 5-ton Payload, Gross Weight 19,340 lb																								
82	32-8	0	9	2.0	34	0.5	0.00	8	1000	6.1	2.2	6.2	3.1	35		0.46	-1	Dd	Kb	Wd				
		1	78			8.5	0.31	12	1500					41	8.6	0.62					6,400	0.33	1000	0.05
83	70-11	0	8	4.7	34	1.9	0.07	5	530	3.2	1.3	2.8	1.3	33		0.25	-9	Fa^{2}Db*	Ka^{2}Kb*	Wa				
		1	28			2.5	0.14	18	2500					170	6.0	0.44					4,900	0.25	2100	0.11
84	122-5	0	7	---	40	0.9	0.00	8	400	3.0	1.3	3.3	1.5	---		0.35	--	Db	Kb	Wa				
		1	34			2.4	0.34	16	3000					---	5.4	0.45					5,500	0.28	2000	0.10
85	150-8	0	5	4.2	30	0.3	0.00	2	80	2.7	1.4	4.0	1.7	12		0.30	-8	Db	Kb	Wa				
		1	36			3.5	0.36	8	3750					67	9.2	0.46					3,400	0.17	2200	0.11
86	220-7	0	1	---	7	0.0	0.00	1	100	3.8	2.0	1.8	1.0	1		0.19	-8	Fa	Ka	Wa				
		1	49			3.7	0.41	29	5660					70	13.2	0.44					4,500	0.23	2400	0.12
Sled, Virgin Snow, 5-ton Payload, Gross Weight 19,340 lb																								
87	32-9	0	10	2.6	30	1.2	0.00	18	1000	6.1	2.2	6.2	3.1	54		0.48	-4	Dd	Kb	Wd				
		1	50			4.5	0.20	12	4000					33	5.0	0.57					7,200	0.37	2700	0.09
88	70-12	0	9	4.2	20	1.7	0.00	8	570	3.2	1.3	2.8	1.3	12		0.28	-1	Fa^{2}Db	Ka^{2}Kb	Wa				
		1	17			2.1	0.02	19	920					67	4.0	0.41					5,200	0.27	2500	0.13
89	122-6	0	8	3.3**	46	0.9	0.00	6	460	3.1	1.3	3.3	1.5	36		0.31	-9	Db	Kb	Wa				
		1	14			0.7	0.00	17	1100					50	3.0	0.40					7,500	0.39	2400	0.12
90	150-9	0	6	4.5	32	0.4	0.02	4	290	2.7	1.4	4.0	1.7	23		0.26	-6	Db	Kb	Wa				
		1	16			0.8	0.07	8	1120					46	5.4	0.39					5,000	0.26	3000	0.16
91	220-8	0	1	---	7	0.0	0.00	1	100	3.7	2.0	1.7	0.9	1		0.19	-8	Fa	Ka	Wa				
		1	10			0.6	0.10	17	2660					64	9.3	0.37					9,000	0.47	2800	0.14
Sled, Compacted Snow, 10-ton Payload, Gross Weight 27,890 lb																								
92	220-10	0	3	6.8	19	0.0	0.00	1	190	---	---	---	---	2		0.24	-8	Fa^{5}Db	Ka^{5}Kb	Wa				
		1	52			2.4	0.30	17	1430					88	9.8	0.45					7,400	0.27	3000	0.11
Sled, Virgin Snow, 10-ton Payload, Gross Weight 27,890 lb																								
93	220-11	0	2	6.8	7	0.0	0.00	1	190	---	---	---	---	2		0.24	-8	Fa^{5}Db	Ka^{5}Kb	Wa				
		1	19			0.9	0.10	13	660					50	9.2	0.42					11,000	0.39	3600	0.13
Sleds, Tandem,† Compacted Snow, 5- and 10-ton Payload, Gross Weight 47,230 lb																								
94	220-12	0	2	6.8	7	0.0	0.00	1	40	---	---	---	---	3		0.17	-8	Fa^{4}Db	Ka^{4}Kb	Wa				
		1	49			2.3	0.30	12	2860					73	9.2	0.45					9,800	0.21	5300	0.11
95	220-13	0	3	---	11	0.0	0.00	1	40	---	---	---	---	3		0.17	-8	Fa^{4}Db	Ka^{4}Kb	Wa				
		1	53			3.2	0.40	32	4000					102	10.8	0.46					9,500	0.20	5300	0.11

Note: Clearance between the bottom of the cross members of the sled is in the order of 6 in. Rut depth in excess of 6 in. gives some idea of the amount of snow which piled up in front of the sled.

* Number designates depth in inches at which a change in snow property occurred.

** Data from compaction characteristics curves.

† Two sleds were hitched in tandem; Item 94 the lead sled was loaded to 5000 lb and the second sled to 10,000 lb. Order was reversed for Item 95.

Table 19

Summary of Results of Towed Vehicle Tests, 1957

Average Before-, During-, and After-Traffic Data

Date	Item No.	Field Test No.	Pass No.	Cone Index	Strength Measurements 0- to 6-in. Depth: 25 Blows Compaction, in.	25 Blows Rating Cone Index	Vane Shear Strength, psi Initial	Vane Shear Strength, psi Residual	Ramm Hardness No.	Canadian Hardness g/cm^2	Rut Depth in.	Snow Measurements 0- to 6-in. Depth: Density g/cm^3	Temp °C	Snow Classification Grain Nature	Snow Classification Hardness	Snow Classification Wetness	Towing Data, Avg: Max Static Pull, lb	Static Coefficient Friction	Kinetic Pull, lb	Kinetic Coefficient Friction
Sleds, Compacted Snow, 5-ton Payload, Gross Weight 19,340 lb																				
Steel																				
11 May	232	14	0	5	3.9	10	2.3	0.23	4	380	7.5	0.31	-7	Db	Ka^{3}Kb*	Wa	4,000$^{(1)}$**	0.21	2170	0.11
			1	44			5.8	0.30	36	5000		0.36								
13 May	233	20	0	12	2.2	16	2.5	0.12	10	1180	5.4	0.38	-13	Db	Ka^{2}Kd^{4}Kb	Wa	7,860	0.41	2750	0.14†
			1	54			5.6	0.42	33	2000		0.44								
20 May	234	60	0	10	2.9	13	2.0	0.13	5	400	5.8	0.32	-4	Db	Kc	Wa	11,200$^{(1)}$	0.58	2270	0.12
			1	32			3.2	0.26	22	300		0.41								
7 June	235	122	0	11	3.0	24	1.0	0.12	6	150	7.4	0.28	-2	Db	Kc	Wc^{3}Wa*	8,400$^{(1)}$	0.43	1965	0.10
			1	32			3.3	0.41	35	400		0.46								
14 June	236	150	0	6	3.0	30	1.2	0.13	2	200	6.0	0.42	0	Db	Kb^{3}Kc	Wc	4,800$^{(1/2)}$	0.25	1500	0.08
			1	69			9.1+	0.78	7	2000		0.64								
23 June	237	189	0	3	3.8	27	---	----	1	200	10.6	0.56	0	Db	Kc	Wd	7,520$^{(1)}$	0.39	1720	0.09
			1	67			---	----	21	2500		0.70								
30 June	238	227	0	3	3.8	41	---	----	1	60	11.0	0.48	0	Db	Ka^{2}Kc^{4}Kb	Wd	8,600$^{(1)}$	0.46	1760	0.09
			1	78			---	----	19	3500		0.66								
7 July	239	251	0	3	3.8	19	---	----	1	170	9.0	0.49	0	Db	Kc^{2}Kb	Wd	8,000$^{(1)}$	0.41	1480	0.08
			1	81			---	----	29	1500		0.63								
Kel-F																				
15 May	240	25	0	16	---	--	2.2	0.12	12	1070	2.8	0.31	-6	Db	Kb^{3}Kd	Wa	5,720	0.30	2240	0.11
			1	60			6.3	0.19	39	3000		0.43								
16 May	241	34	0	8	---	--	1.4	0.12	--	----	6.3	0.34	-4	Db	Kc	Wa	5,000	0.26	2320	0.12
			1	51			5.8	0.42	--	----		0.42								
20 May	242	56	0	19	---	--	2.5	0.13	--	----	4.4	0.35	-5	Db	Kb^{4}Kd	Wa	5,000$^{(1/2)}$	0.26	2030	0.10
			1	38			3.8	0.19	--	----		0.42								
10 June	243	127	0	10	---	--	1.0	0.12	--	----	4.9	0.37	-2	Db	Kc	Wc^{3}Wa	4,000$^{(1)}$	0.21	1360	0.07
			1	52			2.5	0.48	--	----		0.49								
14 June	244	154	0	5	---	--	1.2	0.14	--	----	6.1	0.46	0	Db	Ka^{4}Kc	Wc	3,360$^{(1)}$	0.17	1240	0.06
			1	93			9.4	0.56	--	----		0.59								
23 June	245	183	0	5	---	--	---	----	--	----	9.8	0.50	0	Db	Kb	Wd	3,200$^{(1)}$	0.17	1280	0.07
			1	71			---	----	--	----		0.67								
30 June	246	223	0	2	---	--	---	----	--	----	11.4	0.53	0	Db	Ka^{3}Kc	Wd	4,000$^{(1)}$	0.21	1280	0.07
			1	82			---	----	--	----		0.70								
7 July	247	254	0	3	---	--	---	----	--	----	8.8	0.51	0	Db	Kb	Wd	4,960$^{(1)}$	0.26	980	0.05
			1	83			---	----	--	----		0.68								

(Continued)

Note: Clearance between the bottom of the cross members of the sled is in the order of 6 in. Rut depth in excess of 6 in. gives some idea of the amount of snow which piled up in front of the sled.

* Number designates depth in inches at which a change in snow property occurred.

** Numbers in raised parentheses indicate "freeze-down" time, min.

† Cross member of front sled dragged.

(Sheet 1 of 7 sheets)

Table 19 (Continued)

Date	Item No.	Field Test No.	Pass No.	Strength Measurements 0- to 6-in. Depth: Cone Index	25 Blows: Compaction, in.	25 Blows: Rating Cone Index	Vane Shear Strength, psi: Initial	Vane Shear Strength, psi: Residual	Ramm Hardness No.	Canadian Hardness g/cm^2	Rut Depth in.	Snow Measurements 0- to 6-in. Depth: Density g/cm^3	Temp °C	Snow Classification: Grain Nature	Snow Classification: Hardness	Snow Classification: Wetness	Towing Data, Avg: Max Static Pull, lb	Static Coefficient Friction	Kinetic Pull, lb	Kinetic Coefficient Friction
Sleds, Compacted Snow, 5-ton Payload, Gross Weight 19,340 lb (Continued)																				
Teflon																				
14 May	248	22	0	11	---	--	2.0	0.12	--	----		0.33								
			1	49			5.2	0.36	--	----	5.3	0.44	-5	Db	Kb^{3}Kd	Wa	4,300	0.22	1400	0.07
17 May	249	[illegible]	0	15	---	--	1.8	0.12	--	----		0.33								
			1	33			4.7	0.12	--	----	3.6	0.42	-4	Db	Kb	Wa	2,400(1)	0.12	870	0.04
20 May	250	[illegible]	0	11	---	-	1.3	0.12	--	----		0.36								
			1	31			3.2	0.12	--	----	4.0	0.48	-6	Db	Kb	Wa	3,350(1)	0.17	1400	0.07
10 June	251	131	0	9	---	--	1.2	0.12	--	----		0.36								
			1	56			2.5	0.60	--	----	4.8	0.42	-2	Db	Ka^{1}Kc	Wc^{1}Wa	4,800(1)	0.25	960	0.05
13 June	252	146	0	7	---	--	1.3	0.22	--	----		0.44								
			1	73			9.4	0.54	--	----	6.2	0.60	0	Db	Kb^{3}Kd^{4}Kc	Wc	2,880(1)	0.15	920	0.05
23 June	253	195	0	3	---	--	---	----	--	----		0.44								
			1	73			---	----	--	----	9.6	0.62	-1	Dd	Kc^{1}Kb	Wd	3,440(1)	0.18	960	0.05
30 June	254	219	0	2	---	--	---	----	--	----		0.50								
			1	74			---	----	--	----	11.7	0.68	0	Db	Ka	Wd	3,200(1)	0.17	[illegible]	0.06
7 July	255	258	0	2	---	--	---	----	--	----		0.49								
			1	83			---	----	--	----	9.8	0.64	0	Db	Ka^{4}Kb	Wd	3,040(1)	0.16	820	0.04
Sleds, Virgin Snow, 5-ton Payload, Gross Weight 19,340 lb																				
Steel																				
11 May	256	15	0	13	1.5	13	2.3	0.12	16	370		0.31								
			1	22			3.6	0.35	13	850	4.4	0.38	-7	Db	Ka^{3}Kb	Wa	5,300	0.27	2460	0.13
13 May	257	21	0	7	3.1	14	2.2	0.23	16	1180		0.38								
			1	32			3.2	0.31	14	220	4.2	0.44	-13	Db	Ka^{2}Kd^{4}Kc	Wa	8,200	0.42	2800	0.14
20 May	258	61††	0	8	2.9	18	1.5	0.12	8	400		0.32								
			1	21			2.5	0.18	12	550	4.6	0.40	-4	Db	Kc	Wa	10,000(1/3)	0.52	4200	0.22
7 June	259	123††	0	6	4.0	20	1.0	0.12	5	150		0.28								
			1	37			1.9	0.29	30	450	6.0	0.41	-2	Db	Kc	Wc^{3}Wa	12,000(1)	0.62	4950	0.26
14 June	260	[illegible]	0	8	3.8	49	1.1	0.16	2	200		0.42								
			1	48			6.0	0.62	35	2500	5.0	0.70	0	Db	Kb^{3}Kc	Wc	6,400(1)	0.33	2000	0.10
23 June	261	190	0	4	3.8	36	---	----	2	200		0.56								
			1	44			---	----	17	2250	9.9	0.63	0	Db	Kc	Wd	9,600(1)	0.50	2720	0.14
30 June	262	228	0	3	3.5	37	---	----	1	60		0.48								
			1	54			---	----	19	2500	13.2	0.64	0	Db	Ka^{2}Kc^{4}Kb	Wd	13,000(1)	0.67	3600	0.19
Kel-F																				
15 May	263	26	0	11	---	--	1.7	0.12	8	930		0.37								
			1	37			3.9	0.13	26	3000	2.4	0.43	-6	Db	Kb^{2}Kd^{5}Kc	Wc^{2}Wa	3,930(2/3)	0.20	2300	0.12
16 May	264	35	0	5	---	--	2.2	0.12	--	----		0.34								
			1	26			3.4	0.14	--	----	2.3	0.40	-4	Db	Kc	Wa	5,330	0.28	2200	0.11

(Continued)

†† Snow froze to bottom of sled runners.

(Sheet 2 of 7 sheets)

Table 19 (Continued)

Date	Item No.	Field Test No.	Pass No.	Cone Index	Strength Measurements 0- to 6-in. Depth: 25 Blows: Compaction, in.	25 Blows: Rating Cone Index	Vane Shear Strength, psi: Initial	Vane Shear Strength, psi: Residual	Rama Hardness No.	Canadian Hardness g/cm²	Rut Depth in.	Snow Measurements 0- to 6-in. Depth: Density g/cm³	Temp °C	Snow Classification: Grain Nature	Hardness	Wetness	Towing Data, Avg: Max Static Pull, lb	Static Coefficient Friction	Kinetic Pull, lb	Kinetic Coefficient Friction
Sleds, Virgin Snow, 5-ton Payload, Gross Weight 19,340 lb (Continued)																				
Kel-F (Continued)																				
20 May	265	57	0	10	---	--	2.5	0.12	--	----	2.5	0.35	-5	Db	Kb^4Kd	Wa	$3,200^{(1/2)}$	0.17	2070	0.11
			1	27			3.0	0.19	--	----		0.39								
10 June	266	128	0	10	---	--	1.2	0.17	--	----	2.2	0.37	-2	Db	Kc	Wc^3Wa	$3,360^{(1)}$	0.17	1700	0.09
			1	29			2.0	0.30	--	----		0.46								
14 June	267	155	0	6	---	--	1.3	0.18	--	----	4.2	0.47	0	Db	Ka^4Kc	Wc	$2,500^{(1)}$	0.13	1520	0.08
			1	44			5.2	0.68	--	----		0.62								
23 June	268	184	0	5	---	--	---	----	--	----	9.1	0.50	0	Db	Kb	Wd	$4,800^{(1)}$	0.25	2190	0.11
			1	43			---	----	--	----		0.62								
30 June	269	224	0	3	---	--	---	----	--	----	10.6	0.53	0	Db	Ka^3Kc^5Kb	Wd	$4,960^{(1)}$	0.26	1920	0.10
			1	47			---	----	--	----		0.67								
Teflon																				
14 May	270	23	0	22	---	--	4.7	0.19	--	----	1.9	0.30	-5	Db	Kb^3Kd	Wa	3,800	0.20	1380	0.07
			1	29			4.7	0.22	--	----		0.40								
17 May	271	40	0	10	---	--	1.1	0.12	--	----	2.1	0.33	-4	Db	Kb	Wa	2,630	0.14	1000	0.05
			1	35			2.9	0.12	--	----		0.39								
20 May	272	51	0	11	---	--	1.2	0.12	--	----	2.3	0.36	-6	Db	Kb	Wa	2,730	0.14	1220	0.06
			1	22			2.4	0.12	--	----		0.45								
10 June	273	132	0	8	---	--	0.9	0.12	--	----	2.8	0.36	-2	Db	Ka^1Kc	Wc^3Wa	$3,840^{(1)}$	0.20	1040	0.05
			1	28			1.5	0.24	--	----		0.42								
13 June	274	147	0	8	---	--	1.2	0.12	--	----	3.5	0.44	0	Db	Kb^3Kd^4Kc	Wc	$2,560^{(1)}$	0.13	1200	0.06
			1	36			5.3	0.63	--	----		0.56								
23 June	275	196	0	4	---	--	---	----	--	----	8.3	0.44	0	Db	Kc^1Kb	Wd	$4,160^{(1)}$	0.22	1760	0.09
			1	40			---	----	--	----		0.64								
30 June	276	220	0	2	---	--	---	----	--	----	11.1	0.50	0	Db	Ka	Wd	$5,600^{(1)}$	0.29	2140	0.11
			1	43			---	----	--	----		0.62								
Sleds, Compacted Snow, 10-ton Payload, Gross Weight 27,890 lb																				
Steel																				
11 May	277	16	0	12	---	--	2.0	0.12	--	----	7.2	0.31	-7	Db	Ka^3Kb	Wa	9,100	0.33	3000	0.11
			1	49			4.0	0.32	--	----		0.44								
15 May	278	28	0	17	---	--	4.2	0.16	--	----	4.2	0.34	-4	Db	Kc^3Kd^4Kb	Wc^3Wa	14,930	0.53	5000	0.18
			1	42			3.9	0.23	--	----		0.46								
20 May	279	52	0	24	---	--	3.1	0.12	--	----	4.4	0.38	-7	Db	Kc	Wa	$10,600^{(1)}$	0.38	3550	0.13
			1	50			4.2	0.12	--	----		0.49								
25 May	280	80	0	23	---	--	3.2	0.17	--	----	5.0	0.39	-5	Db	Kc^2Kd	Wa	$17,000^{(2)}$	0.61	3900	0.14
			1	40			4.2	0.28	--	----		0.48								
8 June	281	124	0	9	---	--	1.1	0.12	--	----	9.4	0.28	-2	Db	Kc	Wc^3Wa	$9,200^{(1)}$	0.33	3500	0.12
			1	55			2.7	0.43	--	----		0.48								
14 June	282	156	0	7	---	--	1.0	0.17	--	----	6.8	0.48	0	Db	Ka^4Kc	Wc	$9,600^{(1)}$	0.34	2700	0.10
			1	90			9.5	0.64	--	----		0.62								

(Continued)

(Sheet 3 of 7 sheets)

Table 19 (Continued)

Date	Item No.	Field Test No.	Pass No.	Strength Measurements 0- to 6-in. Depth: Cone Index	25 Blows: Compaction, in.	25 Blows: Rating Cone Index	Vane Shear Strength, psi: Initial	Vane Shear Strength, psi: Residual	Ramm Hardness No.	Canadian Hardness g/cm²	Rut Depth in.	Snow Measurements 0- to 6-in. Depth: Density g/cm³	Temp °C	Snow Classification: Grain Nature	Snow Classification: Hardness	Snow Classification: Wetness	Towing Data, Avg: Max Static Pull, lb	Static Coefficient Friction	Kinetic Pull, lb	Kinetic Coefficient Friction
Sleds, Compacted Snow, 10-ton Payload, Gross Weight 27,890 lb (Continued)																				
Steel (Continued)																				
21 June	283	181	0	5	---	--	---	----	--	----		0.46	0	Db	Kb^{3}Kc	Wc				
			1	90			---	----	--	----	8.7	0.68					8,000(1)	0.29	2450	0.09
30 June	284	215	0	3	---	--	---	----	--	----		0.45	0	Db	Ka	Wd				
			1	84			---	----	--	----	11.3	0.64					10,800(1)	0.39	2480	0.09
7 July	285	256	0	2	---	--	---	----	--	----		0.51	0	Db	Kb	Wd				
			1	95			---	----	--	----	11.3	0.66					11,200(1)	0.40	2240	0.08
Kel-F																				
20 May	286	62	0	11	---	--	1.7	0.12	--	----		0.30	-5	Db	Kb^{4}Kc	Wa				
			1	35			3.4	0.23	--	----	4.2	0.42					7,800(1)	0.28	3550	0.13
24 May	287	89	0	15	---	--	1.7	0.13	--	----		0.35	-6	Db	Kd^{1}Kc^{3}Kd^{4}Kc	Wa				
			1	33			2.9	0.22	--	----	4.1	0.42					8,000(1)	0.29	2840	0.10
8 June	288	120	0	10	---	--	1.3	0.12	--	----		0.28	-2	Db	Kc	Wc^{3}Wa				
			1	64			4.1	0.55	--	----	6.3	0.44					6,720(1)	0.24	2680	0.10
13 June	289	148	0	8	---	--	1.3	0.12	--	----		0.44	0	Db	Kb^{3}Kd^{4}Kc	Wc				
			1	85			9.3+	0.87	--	----	5.8	0.60					4,000(1)	0.14	1680	0.06
23 June	290	187	0	3	---	--	---	----	--	----		0.50	0	Db	Kb	Wd				
			1	89			---	----	--	----	10.2	0.70					4,160(1)	0.15	1600	0.06
30 June	291	229	0	2	---	--	---	----	--	----		0.48	0	Db	Ka^{2}Kc^{4}Kb	Wd				
			1	84			---	----	--	----	11.3	0.66					5,200(1)	0.19	1680	0.06
7 July	292	259	0	2	---	--	---	----	--	----		0.49	0	Db	Kc^{4}Kb	Wd				
			1	87			---	----	--	----	9.7	0.66					5,020(1)	0.18	1220	0.04
Teflon																				
20 May	293	58	0	14	---	--	1.9	0.12	--	----		0.34	-4	Db	Kb^{3}Kd	Wa				
			1	44			3.0	0.18	--	----	5.0	0.42					4,960(1/2)	0.18	1970	0.07
24 May	294	85	0	19	---	--	2.5	0.13	--	----		0.36	-7	Db	Kc	Wa				
			1	35			3.5	0.27	--	----	4.0	0.44					5,760(1)	0.21	2060	0.075
10 June	295	129	0	10	---	--	1.3	0.13	--	----		0.36	-1	Db	Ka^{1}Kc	Wc^{4}Wa				
			1	53			2.7	0.55	--	----	5.4	0.48					5,600(1)	0.20	1560	0.06
14 June	296	152	0	7	---	--	1.1	0.16	--	----		0.42	0	Db	Kb^{3}Kc	Wc				
			1	100			8.9	1.00	--	----	6.4	0.60					5,120(1)	0.18	1560	0.06
23 June	297	193	0	3	---	--	---	----	--	----		0.56	0	Db	Kc	Wd				
			1	88			---	----	--	----	10.1	0.62					4,640(1)	0.17	1720	0.06
30 June	298	231	0	2	---	--	---	----	--	----		0.48	0	Db	Ka^{2}Kc^{4}Kb	Wd				
			1	78			---	----	--	----	11.2	0.66					4,400(1)	0.16	1520	0.06
7 July	299	252	0	3	---	--	---	----	--	----		0.49	0	Db	Kc^{2}Kb	Wd				
			1	86			---	----	--	----	8.6	0.68					6,440(1)	0.23	1160	0.04

(Continued)

(Sheet 4 of 7 sheets)

Table 19 (Continued)

Date	Item No.	Field Test No.	Pass No.	Cone Index	Strength Measurements 0- to 6-in. Depth: 25 Blows Compaction, in.	25 Blows Rating Cone Index	Vane Shear Strength, psi Initial	Vane Shear Strength, psi Residual	Ram Hardness No.	Canadian Hardness g/cm^2	Rut Depth in.	Snow Measurements 0- to 6-in. Depth: Density g/cm^3	Temp °C	Snow Classification Grain Nature	Hardness	Wetness	Towing Data, Avg: Max Static Pull, lb	Static Coefficient Friction	Kinetic Pull, lb	Kinetic Coefficient Friction
Sleds, Virgin Snow, 10-ton Payload, Gross Weight 27,890 lb																				
Steel																				
11 May	300	17	0	25	---	--	3.0	0.12	--	----		0.31	-7	Db	Ka^{3}Kb	Wa				
			1	56			4.3	0.19	--	----	5.4	0.42					11,600	0.42	3800	0.14
15 May	301	29	0	18	---	--	3.3	0.12	--	----		0.34	-6	Db	Kc^{3}Kd^{4}Kb	Wa				
			1	44			5.1	0.20	--	----	4.3	0.48					14,400	0.52	4200	0.15
20 May	302	53	0	26	---	--	3.5	0.12	--	----		0.38	-6	Db	Kc	Wa				
			1	38			3.6	0.12	--	----	3.3	0.41					10,900(1/6)	0.39	4070	0.15
23 May	303	81	0	13	---	--	2.1	0.15	--	----		0.39	-4	Db	Kc^{2}Kd	Wa				
			1	33			3.7	0.26	--	----	3.6	0.40					13,200(1)	0.47	4800	0.17
8 June	304	125††	0	5	---	--	0.8	0.12	--	----		0.28	-2	Db	Kc	Wc^{3}Wa				
			1	31			2.0	0.28	--	----	7.8	0.46					15,200(1)	0.54	6920	0.25
14 June	305	157	0	7	---	--	1.2	0.23	--	----		0.48	0	Db	Ka^{4}Kc	Wc				
			1	69			8.4	0.75	--	----	7.8	0.66					11,200(1)	0.40	3600	0.13
21 June	306	182	0	4	---	--	---	----	--	----		0.46	0	Db	Kb^{3}Kc	Wc				
			1	58			---	----	--	----	9.1	0.68					14,800(1)	0.53	3440	0.12
30 June	307	216	0	3	---	--	---	----	--	----		0.45	0	Db	Ka	Wd				
			1	58			---	----	--	----	15.0	0.66					16,000(2)	0.57	4600	0.15
Kel-F																				
20 May	308	63	0	14	---	--	1.8	0.13	--	----		0.30	-4	Db	Kb^{4}Kc	Wa				
			1	29			3.4	0.19	--	----	3.2	0.47					5,200(1)	0.19	3400	0.12
21 May	309	90	0	19	---	--	2.4	0.13	--	----		0.36	-6	Db	Kc^{1}Kd^{5}Kc	Wa				
			1	41			3.4	0.23	--	----	3.0	0.42					6,400(1)	0.23	3060	0.11
8 June	310	121	0	9	---	--	1.2	0.12	--	----		0.28	-2	Db	Kc	Wc^{3}Wa				
			1	47			3.8	0.42	--	----	4.2	0.48					7,360(1)	0.26	3160	0.11
13 June	311	149	0	9	---	--	1.3	0.16	--	----		0.52	0	Db	Ka^{3}Kc	Wc				
			1	51			7.0+	0.63	--	----	4.3	0.58					4,320(1)	0.15	2200	0.08
23 June	312	188	0	4	---	--	---	----	--	----		0.50	0	Db	Kb	Wd				
			1	56			---	----	--	----	11.7	0.66					7,600(1)	0.27	3200	0.12
30 June	313	230	0	2	---	--	---	----	--	----		0.48	0	Db	Ka^{2}Kc^{4}Kb	Wd				
			1	57			---	----	--	----	12.7	0.66					6,800(1)	0.24	3120	0.11
Teflon																				
20 May	314	59	0	9	---	--	2.0	0.13	--	----		0.34	-5	Db	Kb^{3}Kd	Wa				
			1	32			3.5	0.26	--	----	3.6	0.45					5,120(1/2)	0.18	2190	0.08
24 May	315	86	0	25	---	--	3.2	0.15	--	----		0.36	-7	Db	Kc	Wa				
			1	35			4.1	0.22	--	----	1.8	0.43					3,680(1)	0.13	1400	0.05
10 June	316	132	0	9	---	--	1.2	0.13	--	----		0.36	-1	Kb	Ka^{1}Kc	Wc^{4}Wa				
			1	43			1.9	0.40	--	----	3.8	0.44					4,800(1)	0.17	1960	0.07
14 June	317	153	0	6	---	--	1.0	0.12	--	----		0.42	0	Db	Kb^{3}Kc	Wc				
			1	59			5.8	0.72	--	----	4.9	0.56					4,640(1)	0.17	2080	0.08
23 June	318	194	0	3	---	--	---	----	--	----		0.56	0	Db	Kc	Wd				
			1	56			---	----	--	----	10.4	0.62					6,720(1)	0.24	2480	0.09
30 June	319	232	0	2	---	--	---	----	--	----		0.48	0	Db	Ka^{2}Kc^{1}Kb	Wd				
			1	62			---	----	--	----	13.0	0.66					6,800(1)	0.24	3280	0.12

†† Snow froze to bottom of sled runners.

(Continued)

(Sheet 5 of 7 sheets)

Table 19 (Continued)

Date	Item No.	Field Test No.	Pass No.	Cone Index	Strength Measurements 0- to 6-in. Depth: 25 Blows Compaction, in.	25 Blows Rating Cone Index	Vane Shear Strength, psi Initial	Vane Shear Strength, psi Residual	Ram Hardness No.	Canadian Hardness g/cm²	Rut Depth in.	Snow Measurements 0- to 6-in. Depth: Density g/cm³	Temp °C	Snow Classification Grain Nature	Hardness	Wetness	Towing Data, Avg: Max Static Pull, lb	Static Coefficient Friction	Kinetic Pull, lb	Kinetic Coefficient Friction
Sleds, Compacted Snow, 15-ton Payload, Gross Weight 38,190 lb																				
Steel																				
20 May	320	54	0	22	---	--	2.6	0.12	--	----		0.34	-6	Db	Kb^3Kd	Wa				
			1	55			3.9	0.12	--	----	5.9	0.43					$12,800^{(1/3)}$	0.34	5060	0.13
24 May	321	87	0	14	---	--	1.6	0.13	--	----		0.34	-6	Db	$Kd^1Kc^3Kd^4Kc$	Wa				
			1	55			3.7	0.27	--	----	7.4	0.48					$13,760^{(1)}$	0.36	4600	0.12
17 June	322	163	0	11	---	--	---	----	--	----		0.50	0	Db	Kb^4Kc	Wc				
			1	103			---	----	--	----	8.7	0.64					$14,000^{(1)}$	0.37	2800	0.07
23 June	323	191	0	3	---	--	---	----	--	----		0.56	0	Db	Kc	Wd				
			1	96			---	----	--	----	11.1	0.66					$15,600^{(1)}$	0.41	3800	0.10
30 June	324	221	0	2	---	--	---	----	--	----		0.50	0	Db	Ka	Wd				
			1	96			---	----	--	----	11.4	0.62					$16,200^{(1)}$	0.42	3400	0.09
7 July	325	253	0	3	---	--	---	----	--	----		0.49	0	Db	Kc^2Kb	Wd				
			1	104			---	----	--	----	9.0	0.66					$13,200^{(1)}$	0.35	2450	0.06
Kel-F																				
20 May	326	66	0	21	---	--	2.5	0.12	--	----		0.38	-5	Db	Kb^3Kc	Wa				
			1	44			3.7	0.22	--	----	4.4	0.42					$8,400^{(1)}$	0.22	4130	0.11
23 May	327	82	0	17	---	--	2.3	0.17	--	----		0.33	-5	Db	Kc^3Kd	Wa				
			1	39			4.0	0.30	--	----	4.4	0.48					$10,800^{(1)}$	0.28	4000	0.10
23 June	328	197	0	7	---	--	---	----	--	----		0.44	-1	Db	Kc^1Kb	Wd				
			1	93			---	----	--	----	10.2	0.69					$7,400^{(1)}$	0.19	2380	0.06
30 June	329	217	0	2	---	--	---	----	--	----		0.45	0	Db	Ka	Wd				
			1	90			---	----	--	----	12.[illegible]	0.68					$6,800^{(1)}$	0.18	3320	0.09
7 July	330	257	0	2	---	--	---	----	--	----		0.49	0	Db	Ka^4Kb	Wd				
			1	71			---	----	--	----	9.4	0.70					$5,200^{(1)}$	0.14	1920	0.05
Teflon																				
20 May	331	64	0	13	---	--	2.1	0.12	--	----		0.35	-5	Db	Kb^4Kd	Wa				
			1	41			3.1	0.23	--	----	4.7	0.42					$4,640^{(1-1/4)}$	0.12	3290	0.09
24 May	332	92	0	17	---	--	2.0	0.13	--	----		0.36	-5	Db	Kc^1Kd^5Kc	Wa				
			1	45			3.6	0.28	--	----	4.0	0.46					$6,560^{(1-1/4)}$	0.17	2110	0.05
17 June	333	165	0	8	---	--	---	----	--	----		0.52	0	Db	Kc	Wc				
			1	92			---	----	--	----	7.0	0.63					$4,800^{(1)}$	0.13	1900	0.05
23 June	334	195	0	3	---	--	---	----	--	----		0.50	0	Db	Kb	Wd				
			1	94			---	----	--	----	10.7	0.68					$6,080^{(1)}$	0.16	1940	0.05
30 June	335	225	0	2	---	--	---	----	--	----		0.53	0	Db	Ka^3Kc^5Kb	Wd				
			1	103			---	----	--	----	12.0	0.71					$6,800^{(1)}$	0.18	2000	0.05
7 July	336	[illegible]	0	2	---	--	---	----	--	----		0.51	0	Db	Kb	Wd				
			1	39			---	----	--	----	9.4	0.68					$6,600^{(1)}$	0.17	1440	0.04

(Continued)

(Sheet 6 of 7 sheets)

Table 19 (Concluded)

Date	Item No.	Field Test No.	Pass No.	Cone Index	Strength Measurements 0- to 6-in. Depth: 25 Blows Compaction, in.	25 Blows Rating Cone Index	Vane Shear Strength, psi Initial	Vane Shear Strength, psi Residual	Ram Hardness No.	Canadian Hardness g/cm^2	Rut Depth in.	Snow Measurements 0- to 6-in. Depth: Density g/cm3	Temp °C	Snow Classification Grain Nature	Snow Classification Hardness	Snow Classification Wetness	Towing Data, Avg: Max Static Pull, lb	Static Coefficient Friction	Kinetic Pull, lb	Kinetic Coefficient Friction
Sleds, Virgin Snow, 15-ton Payload, Gross Weight 38,190 lb																				
Steel																				
20 May	337	45	0	20	---	--	2.7	0.12	--	----		0.36	-5	Db	Kb^3Kd	Wa				
			1	45			3.8	0.16	--	----	6.1	0.43					13,600(1/3)	0.36	6400	0.17
24 May	338	88	0	12	---	--	2.0	0.12	--	----		0.34	-6	Db	$Kd^1Kc^3Kd^4Kc$	Wa				
			1	41			3.8	0.26	--	----	4.0	0.47					10,000(1)	0.26	4800	0.12
17 June	339	164	0	11	---	--	---	----	--	----		0.50	0	Db	Kb^4Kc	Wc				
			1	82			---	----	--	----	9.3	0.58					18,400(1)	0.48	5100	0.13
23 June	340	192	0	4	---	--	---	----	--	----		0.56	0	Db	Kc	Wd				
			1	67			---	----	--	----	14.4	0.67					17,600(1)	0.46	5600	0.15
30 June	341	222††	0	3	---	--	---	----	--	----		0.50	0	Db	Ka	Wd				
			1	78			---	----	--	----	17.8	0.66					20,800(1)	0.54	8000	0.21
Kel-F																				
20 May	342	67	0	21	---	--	2.7	0.12	--	----		0.38	-5	Db	Kb^3Kc	Wa				
			1	33			3.5	0.19	--	----	4.0	0.45					8,400(1)	0.22	4330	0.11
23 May	343	83	0	20	---	--	2.4	0.16	--	----		0.33	-4	Db	Kc^3Kd	Wa				
			1	31			3.4	0.32	--	----	3.4	0.47					8,400(1-1/4)	0.22	3950	0.10
23 June	344	198	0	4	---	--	---	----	--	----		0.44	-1	Db	Kc^1Kb	Wd				
			1	56			---	----	--	----	13.0	0.65					9,000(1)	0.24	4400	0.12
30 June	345	218	0	2	---	--	---	----	--	----		0.45	0	Db	Ka	Wd				
			1	63			---	----	--	----	14.0	0.64					11,200(1)	0.29	4400	0.12
Teflon																				
20 May	346	65	0	14	---	--	1.8	0.14	--	----		0.35	-5	Db	Kb^4Kd	Wa				
			1	32			2.5	0.30	--	----	4.6	0.44					7,400(1)	0.19	4270	0.11
24 May	347	92	0	18	---	--	2.7	0.14	--	----		0.36	-5	Db	Kc^1Kd^5Kc	Wa				
			1	40			3.4	0.23	--	----	3.3	0.44					5,440(1)	0.14	2520	0.07
17 June	348	166	0	8	---	--	---	----	--	----		0.52	0	Db	Kc	Wc				
			1	62			---	----	--	----	8.0	0.57					6,000(1)	0.16	2800	0.07
23 June	349	186	0	4	---	--	---	----	--	----		0.50	0	Db	Kb	Wd				
			1	64			---	----	--	----	12.8	0.65					10,000(1)	0.26	3800	0.10
30 June	350	226	0	3	---	--	---	----	--	----		0.53	0	Db	Ka^3Kc^5Kb	Wd				
			1	71			---	----	--	----	15.1	0.64					10,800(1)	0.28	4400	0.12
Tracked Vehicles, Athey Wagon, 6-ton Payload, Gross Weight 22,460 lb																				
17 May	351	38	0	18	---	--	1.5	0.12	--	----		0.30	-3	Db	Kb^5Kc	Wa				
			1	61			3.9	0.13	--	----	3.8	0.44					4,000	0.26	2560	0.16
22 May	352	75	0	16	---	--	2.4	0.16	--	----		0.33	-5	Db	Kc^6Kd	Wa				
			1	63			4.1	0.41	--	----	9.6	0.45					7,200	0.32	5330	0.24
17 June	353	162	0	10	---	--	---	----	--	----		0.44	0	Db	Kd^3Kc	Wc				
			1	116			---	----	--	----	13.6	0.60					9,200	0.41	4660	0.21
29 June	354	214	0	2	---	--	---	----	--	----		0.49	0	Db	Kb	Wd				
			1	100			---	----	--	----	19.4	0.64					8,930	0.40	5200	0.23

†† Snow froze to bottom of sled runners.

(Sheet 7 of 7 sheets)

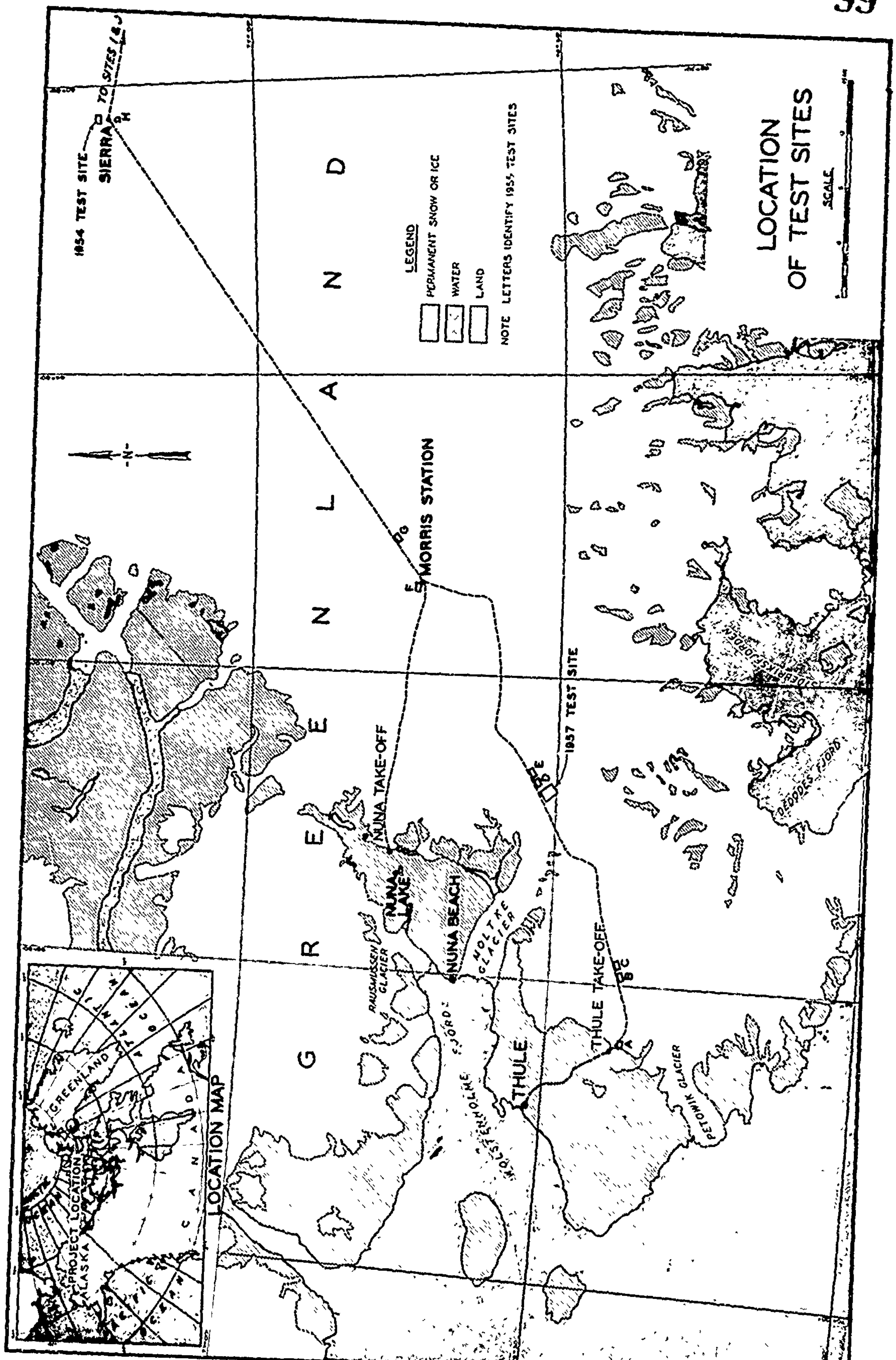

LOCATION OF TEST SITES
SCALE
LEGEND
PERMANENT SNOW OR ICE
WATER
LAND
NOTE LETTERS IDENTIFY 1955 TEST SITES
1954 TEST SITE
SIERRA
G R E E N L A N D
MORRIS STATION
1957 TEST SITE
NUNA TAKE-OFF
NUNA LAKE
NUNA BEACH
MOLTKE GLACIER
THULE TAKE-OFF
THULE
PETOWIK GLACIER
GEDDES FJORD
LOCATION MAP
PROJECT LOCATION
GREENLAND
ALASKA
CANADA

PLATE I

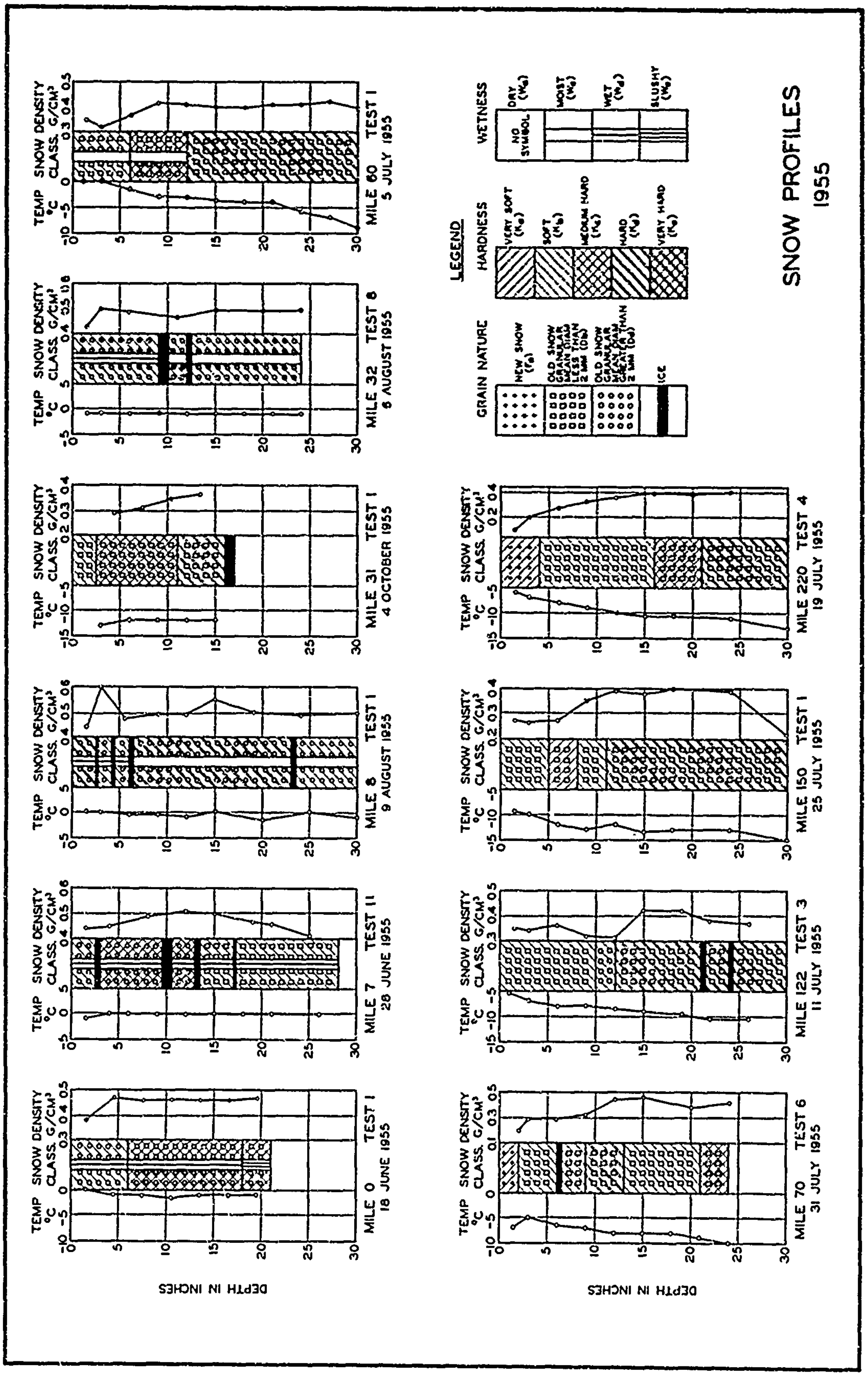

SNOW PROFILES
1955
LEGEND
GRAIN NATURE
NEW SNOW
OLD SNOW GRANULAR MEAN DIAM LESS THAN 2 MM
OLD SNOW GRANULAR MEAN DIAM GREATER THAN 2 MM
ICE
HARDNESS
VERY SOFT
SOFT
MEDIUM HARD
HARD
VERY HARD
WETNESS
NO SYMBOL
DRY
MOIST
WET
SLUSHY
TEMP °C
SNOW CLASS.
DENSITY G/CM³
DEPTH IN INCHES
MILE 0 18 JUNE 1955 TEST I
MILE 7 28 JUNE 1955 TEST II
MILE 8 9 AUGUST 1955 TEST I
MILE 31 4 OCTOBER 1955 TEST I
MILE 32 6 AUGUST 1955 TEST 8
MILE 60 5 JULY 1955 TEST I
MILE 70 31 JULY 1955 TEST 6
MILE 122 11 JULY 1955 TEST 3
MILE 150 25 JULY 1955 TEST I
MILE 220 19 JULY 1955 TEST 4

PLATE 2

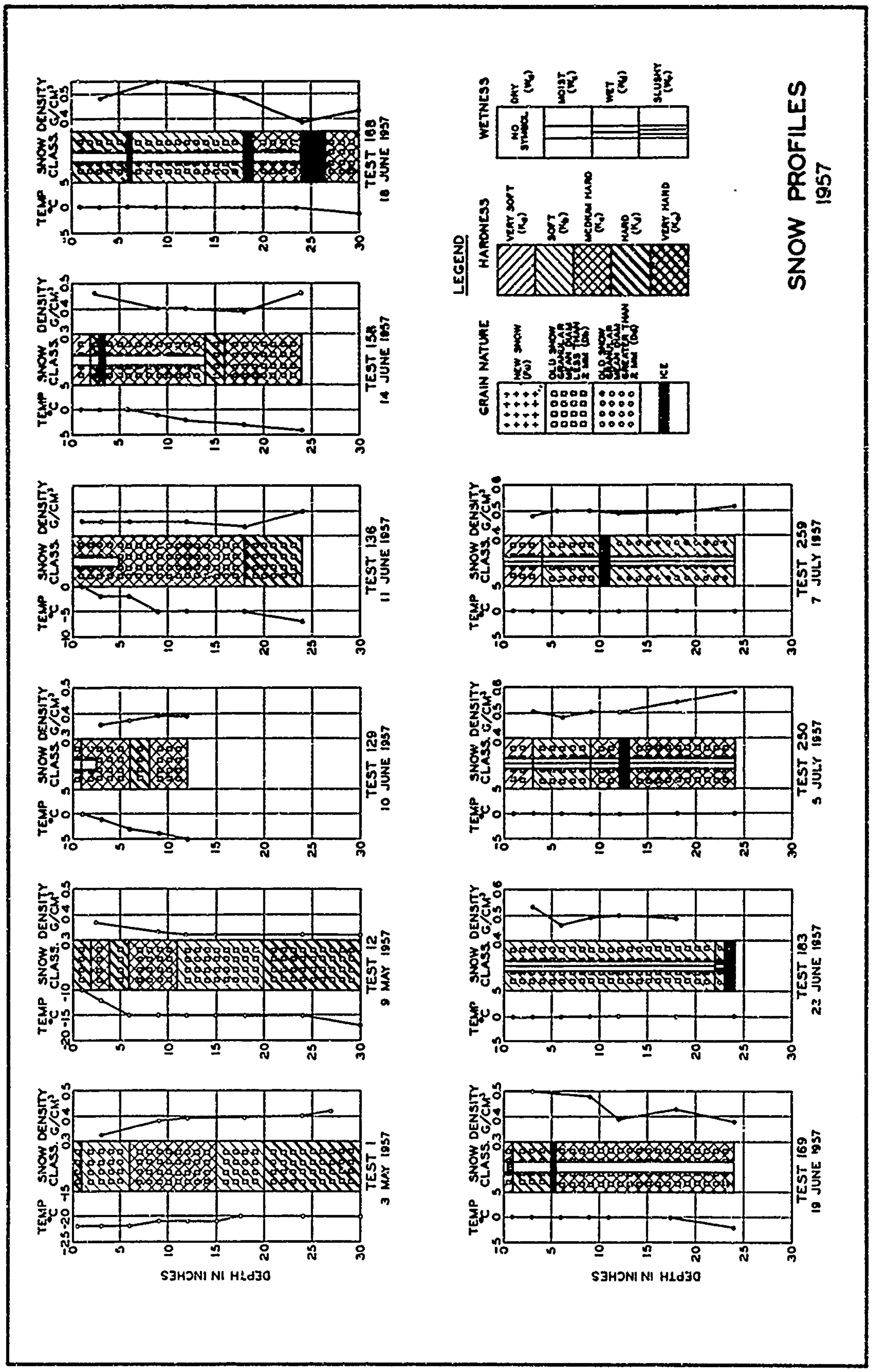
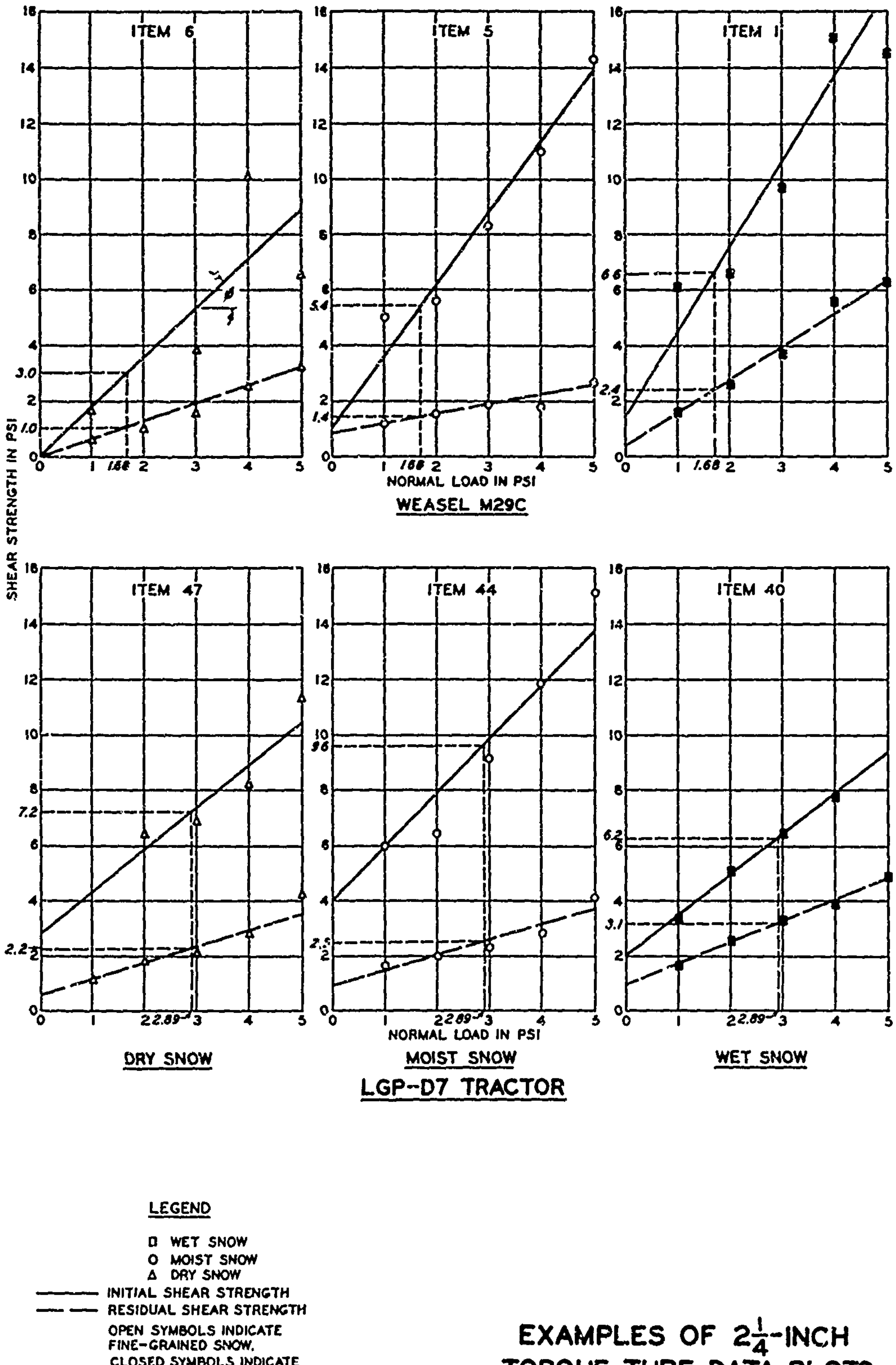

SNOW PROFILES
1957
LEGEND
GRAIN NATURE
NEW SNOW
OLD SNOW GRANULAR MEAN DIAM LESS THAN 2 MM
OLD SNOW GRANULAR MEAN DIAM GREATER THAN 2 MM
ICE
HARDNESS
VERY SOFT
SOFT
MEDIUM HARD
HARD
VERY HARD
WETNESS
NO SYMBOL
DRY
MOIST
WET
SLUSHY
TEMP °C
SNOW CLASS.
DENSITY G/CM³
DEPTH IN INCHES
TEST 1
3 MAY 1957
TEST 12
9 MAY 1957
TEST 129
10 JUNE 1957
TEST 136
11 JUNE 1957
TEST 158
14 JUNE 1957
TEST 168
18 JUNE 1957
TEST 169
19 JUNE 1957
TEST 183
22 JUNE 1957
TEST 250
5 JULY 1957
TEST 259
7 JULY 1957

PLATE 3



EXAMPLES OF $2\frac{1}{4}$-INCH TORQUE TUBE DATA PLOTS

(NOT-MOVED POSITION)

PLATE 4

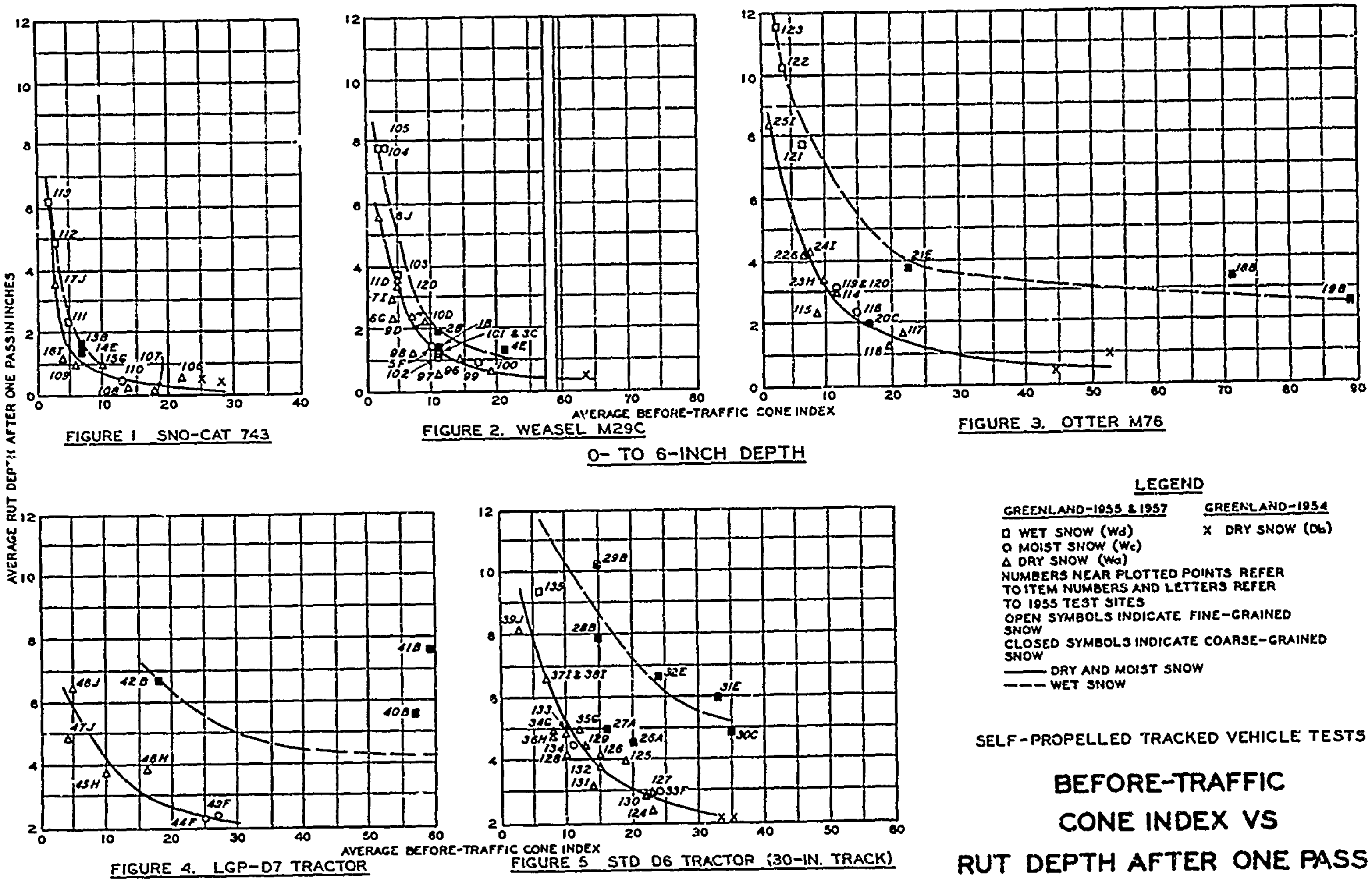


FIGURE 1 SNO-CAT 743

FIGURE 2. WEASEL M29C

FIGURE 3. OTTER M76

0- TO 6-INCH DEPTH

FIGURE 4. LGP-D7 TRACTOR

FIGURE 5 STD D6 TRACTOR (30-IN. TRACK)

0- TO 12-INCH DEPTH

SELF-PROPELLED TRACKED VEHICLE TESTS

BEFORE-TRAFFIC CONE INDEX VS RUT DEPTH AFTER ONE PASS

SHEET 1 OF 2

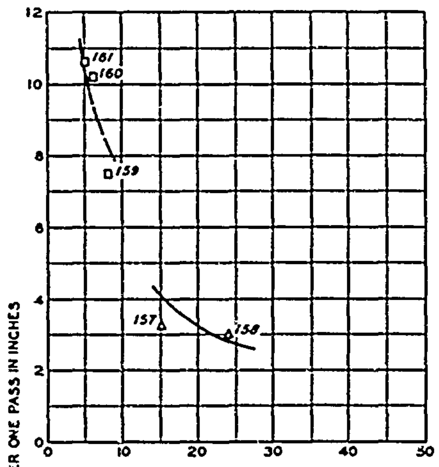


FIGURE 6 LGP-D8 TRACTOR

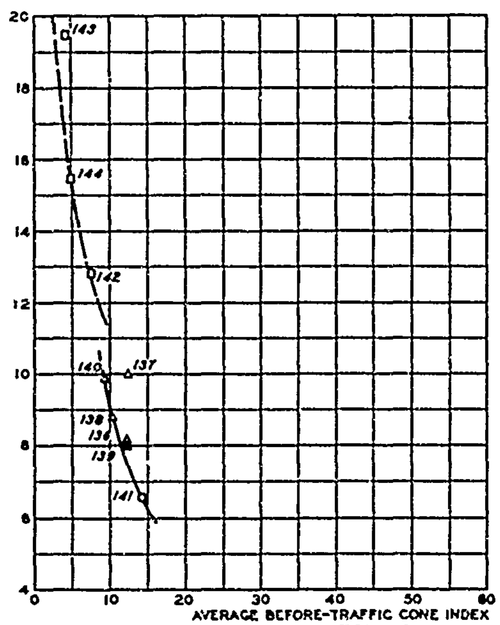


FIGURE 7. HI-SPEED TRACTOR M5A4

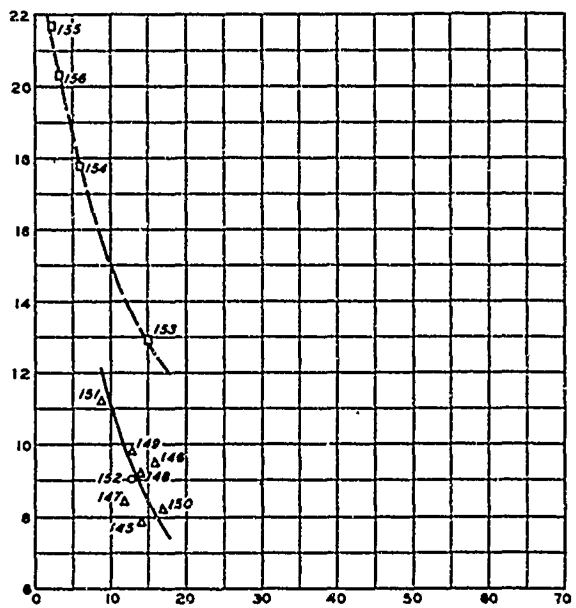


FIGURE 8. HI-SPEED TRACTOR M4

0- TO 12-INCH DEPTH

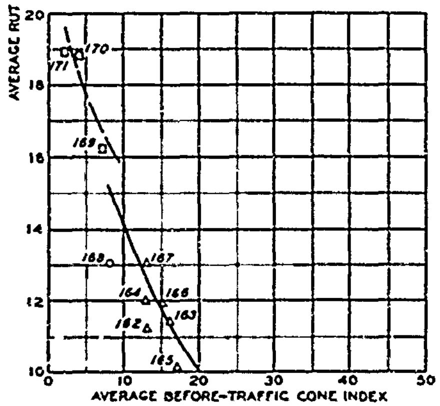


FIGURE 9 MEDIUM TANK M48

0- TO 12-INCH DEPTH

LEGEND

□ WET SNOW (Wd)
○ MOIST SNOW (Wc)
△ DRY SNOW (Wa)

NUMBERS NEAR PLOTTED POINTS REFER TO ITEM NUMBERS AND LETTERS REFER TO 1955 TEST SITES
OPEN SYMBOLS INDICATE FINE-GRAINED SNOW
CLOSED SYMBOLS INDICATE COARSE-GRAINED SNOW
——— DRY AND MOIST SNOW
– – – WET SNOW

SELF-PROPELLED TRACKED VEHICLE TESTS

BEFORE-TRAFFIC CONE INDEX VS RUT DEPTH AFTER ONE PASS

SHEET 2 OF 2

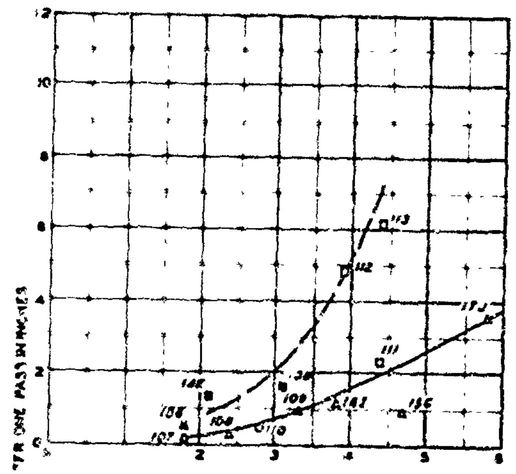


FIGURE 1 SNO-CAT 743

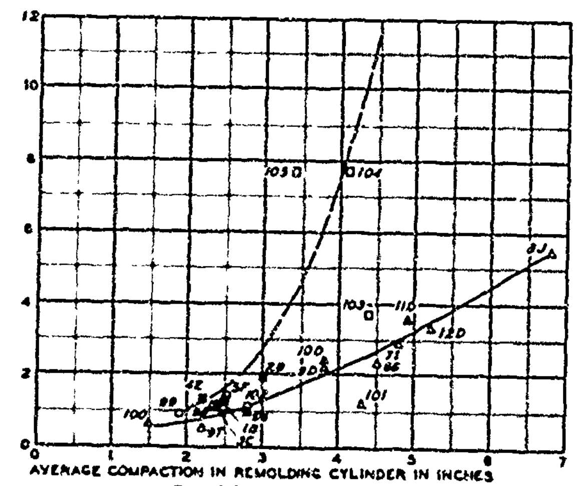


FIGURE 2 WEASEL M29C

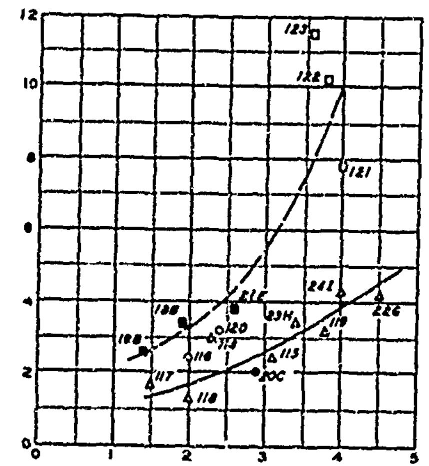


FIGURE 3 OTTER M76

25-BLOW COMPACTION EFFORT

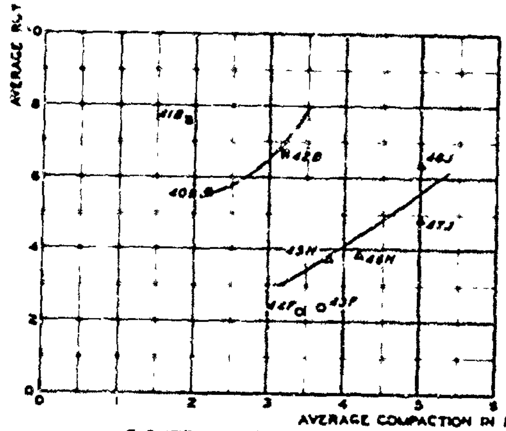


FIGURE 4 LGP-D7 TRACTOR

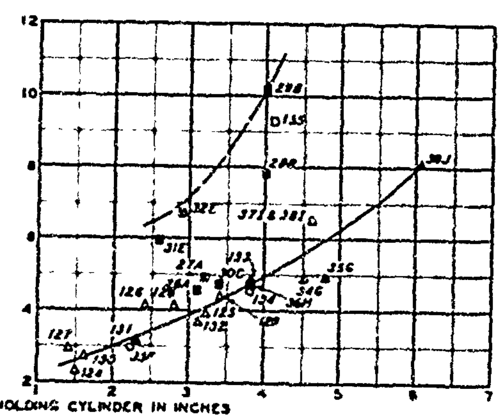


FIGURE 5 STD D6 TRACTOR (30-IN. TRACK)

50-BLOW COMPACTION EFFORT

LEGEND

□ WET SNOW (W_d)
○ MOIST SNOW (W_c)
△ DRY SNOW (W_a)

NUMBERS NEAR PLOTTED POINTS REFER TO ITEM NUMBERS AND LETTERS REFER TO 1955 TEST SITES

OPEN SYMBOLS INDICATE FINE-GRAINED SNOW

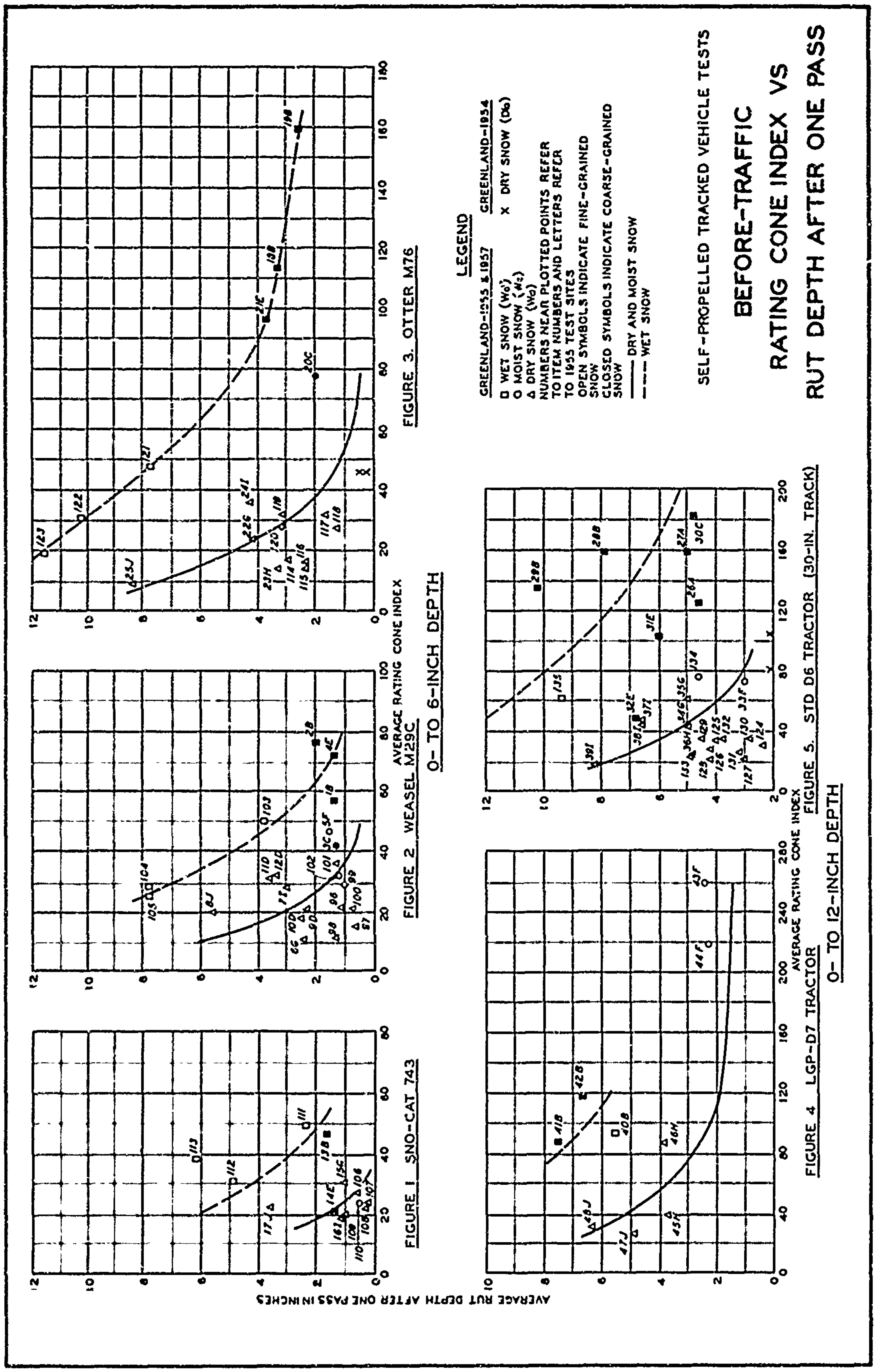
CLOSED SYMBOLS INDICATE COARSE-GRAINED SNOW

—— DRY AND MOIST SNOW

– – – WET SNOW

SELF-PROPELLED TRACKED VEHICLE TESTS

BEFORE-TRAFFIC COMPACTION IN REMOLDING CYLINDER VS RUT DEPTH AFTER ONE PASS



SELF-PROPELLED TRACKED VEHICLE TESTS
BEFORE-TRAFFIC
RATING CONE INDEX VS
RUT DEPTH AFTER ONE PASS
LEGEND
GREENLAND-1955 & 1957
□ WET SNOW (Wc)
O MOIST SNOW (Mc)
Δ DRY SNOW (Wc)
GREENLAND-1954
X DRY SNOW (Dc)
NUMBERS NEAR PLOTTED POINTS REFER TO ITEM NUMBERS AND LETTERS REFER TO 1955 TEST SITES
OPEN SYMBOLS INDICATE FINE-GRAINED SNOW
CLOSED SYMBOLS INDICATE COARSE-GRAINED SNOW
DRY AND MOIST SNOW
WET SNOW
AVERAGE RUT DEPTH AFTER ONE PASS IN INCHES
AVERAGE RATING CONE INDEX
FIGURE 1 SNO-CAT 743
FIGURE 2 WEASEL M29C
FIGURE 3 OTTER M76
0- TO 6-INCH DEPTH
FIGURE 4 LGP-D7 TRACTOR
FIGURE 5 STD D6 TRACTOR (30-IN. TRACK)
0- TO 12-INCH DEPTH

PLATE 7

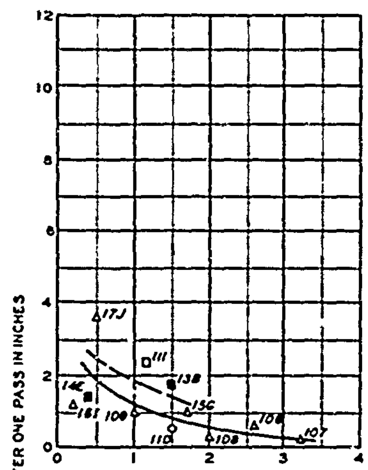


FIGURE 1. SNO-CAT 743

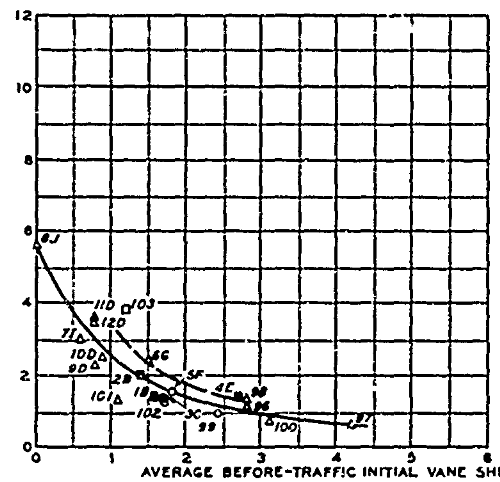


FIGURE 2. WEASEL M29C

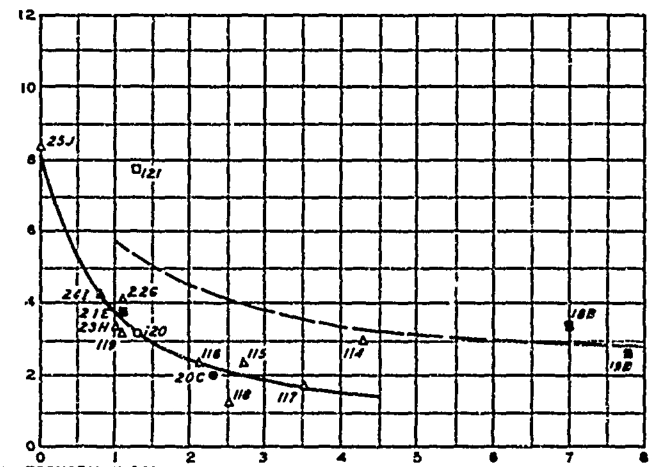


FIGURE 3. OTTER M76

0- TO 6-INCH DEPTH

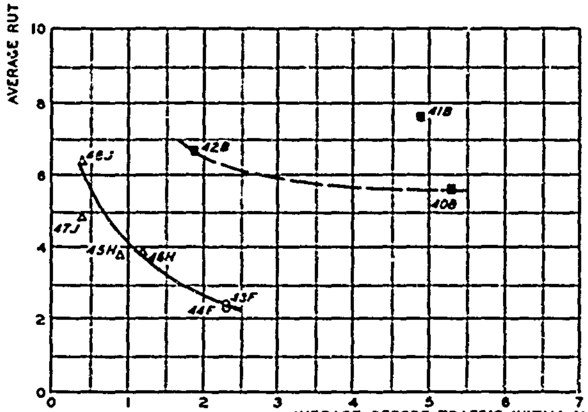


FIGURE 4. LGP-D7 TRACTOR

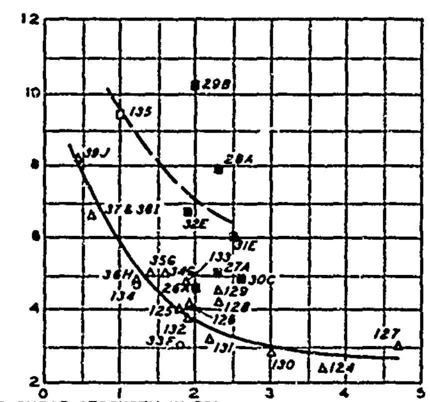


FIGURE 5. STD D8 TRACTOR (30-IN. TRACK)

0- TO 12-INCH DEPTH

LEGEND

□ WET SNOW (W_d)
○ MOIST SNOW (W_c)
△ DRY SNOW (W_a)

NUMBERS NEAR PLOTTED POINTS REFER TO ITEM NUMBERS AND LETTERS REFER TO 1955 TEST SITES
OPEN SYMBOLS INDICATE FINE-GRAINED SNOW
CLOSED SYMBOLS INDICATE COARSE-GRAINED SNOW
—— DRY AND MOIST SNOW
---- WET SNOW

SELF-PROPELLED TRACKED VEHICLE TESTS

BEFORE-TRAFFIC INITIAL VANE SHEAR STRENGTH VS RUT DEPTH AFTER ONE PASS

SHEET 1 OF 2

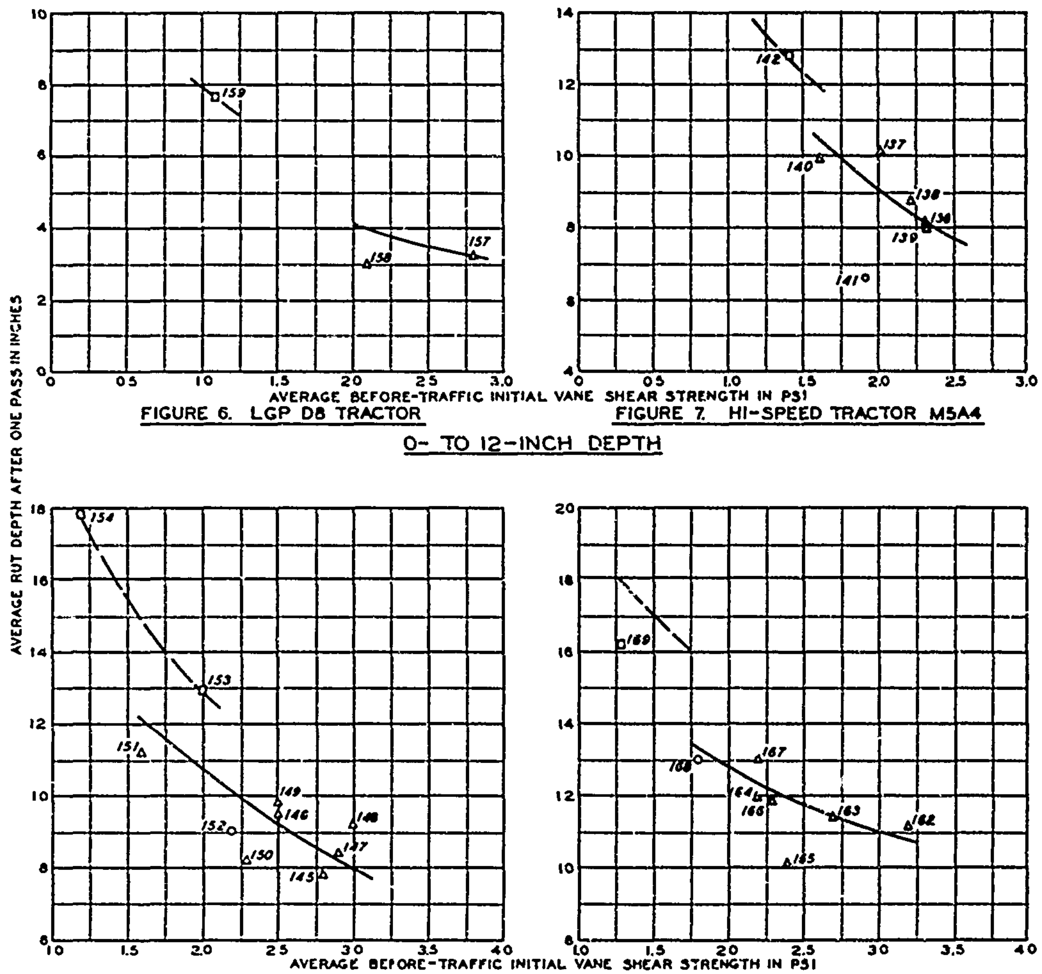


FIGURE 6. LGP D8 TRACTOR

FIGURE 7. HI-SPEED TRACTOR M5A4

0- TO 12-INCH DEPTH

FIGURE 8. HI-SPEED TRACTOR M4

FIGURE 9 MEDIUM TANK M 48

0- TO 12-INCH DEPTH

LEGEND

□ WET SNOW (W_s)
○ MOIST SNOW (W_c)
△ DRY SNOW (W_d)
NUMBERS NEAR PLOTTED POINTS REFER TO ITEM NUMBERS AND LETTERS REFER TO 1955 TEST SITES
OPEN SYMBOLS INDICATE FINE-GRAINED SNOW
CLOSED SYMBOLS INDICATE COARSE-GRAINED SNOW
——— DRY AND MOIST SNOW
– – – WET SNOW

SELF-PROPELLED TRACKED VEHICLE TESTS

BEFORE-TRAFFIC INITIAL VANE SHEAR STRENGTH VS RUT DEPTH AFTER ONE PASS

SHEET 2 OF 2

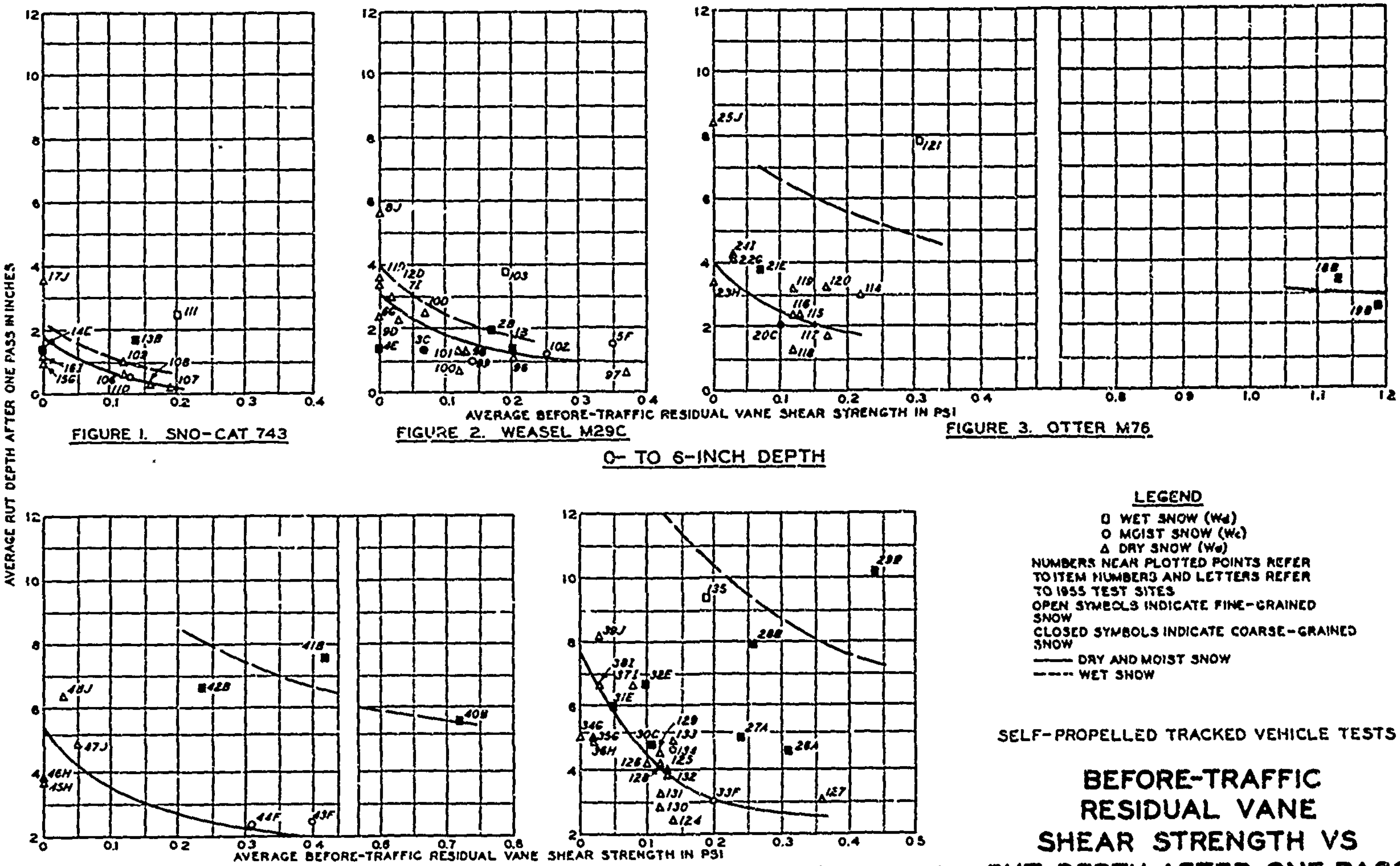


FIGURE 1. SNO-CAT 743

FIGURE 2. WEASEL M29C

FIGURE 3. OTTER M76

0- TO 6-INCH DEPTH

FIGURE 4. LGP-D7 TRACTOR

FIGURE 5. STD D6 TRACTOR (30-IN TRACK)

0- TO 12-INCH DEPTH

LEGEND

□ WET SNOW (Wd)
○ MOIST SNOW (Wc)
△ DRY SNOW (Wa)

NUMBERS NEAR PLOTTED POINTS REFER TO ITEM NUMBERS AND LETTERS REFER TO 1955 TEST SITES

OPEN SYMBOLS INDICATE FINE-GRAINED SNOW

CLOSED SYMBOLS INDICATE COARSE-GRAINED SNOW

—— DRY AND MOIST SNOW

– – – WET SNOW

SELF-PROPELLED TRACKED VEHICLE TESTS

BEFORE-TRAFFIC RESIDUAL VANE SHEAR STRENGTH VS RUT DEPTH AFTER ONE PASS

SHEET 1 OF 2

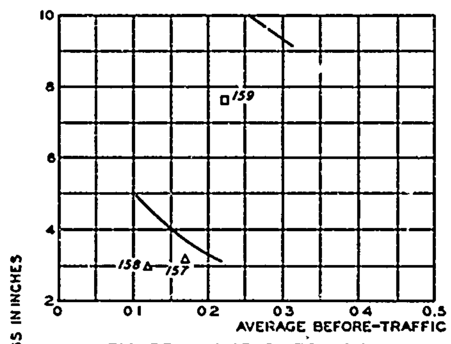


FIGURE 6. LGP-D8 TRACTOR

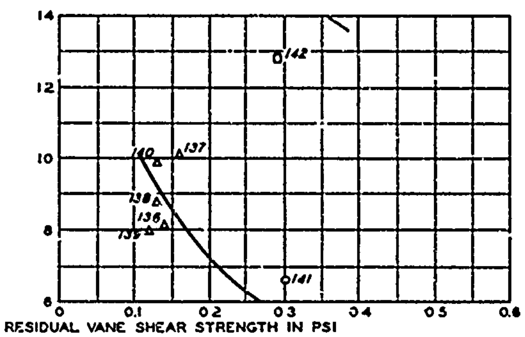


FIGURE 7. HI-SPEED TRACTOR M5A4

0- TO 12-INCH DEPTH

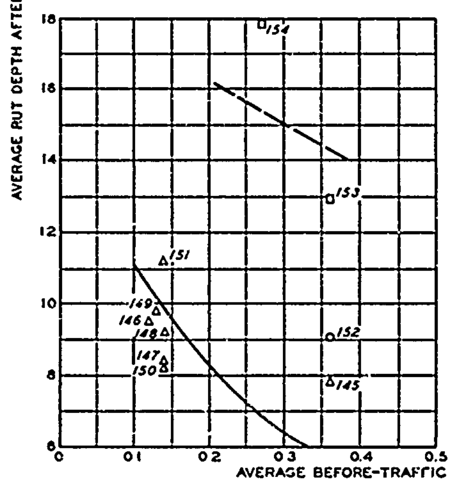


FIGURE 8 HI-SPEED TRACTOR M4

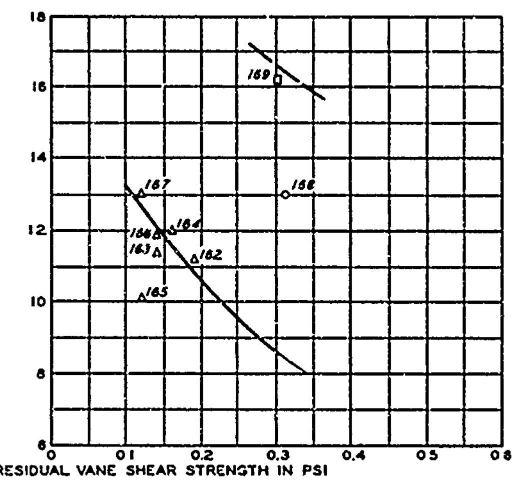


FIGURE 9 MEDIUM TANK M48

0- TO 12-INCH DEPTH

LEGEND

□ WET SNOW (Wd)
○ MOIST SNOW (Wc)
△ DRY SNOW (Wa)

NUMBERS NEAR PLOTTED POINTS REFER TO ITEM NUMBERS AND LETTERS REFER TO 1955 TEST SITES

OPEN SYMBOLS INDICATE FINE-GRAINED SNOW

CLOSED SYMBOLS INDICATE COARSE-GRAINED SNOW

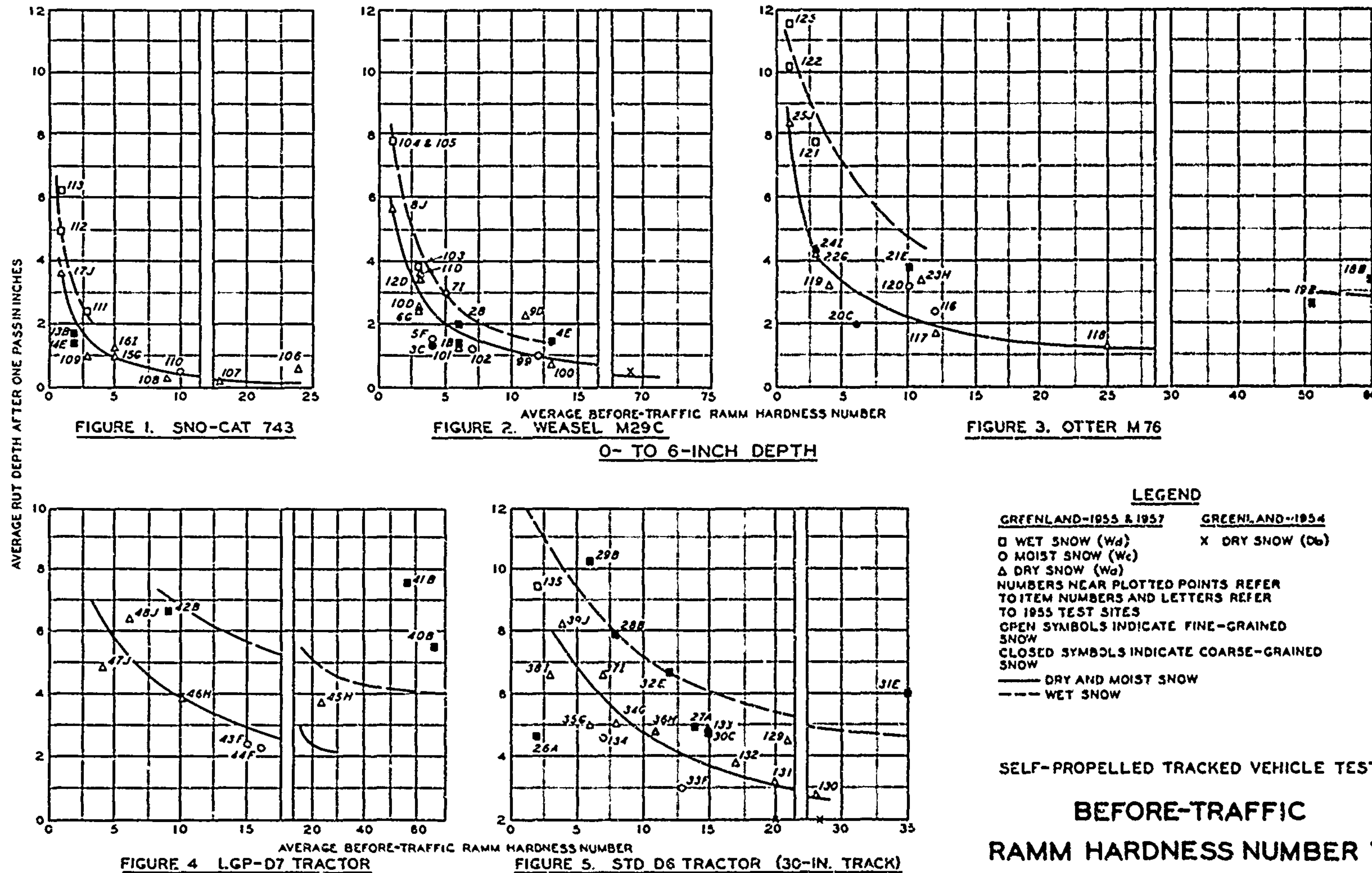
——— DRY AND MOIST SNOW

– – – WET SNOW

SELF-PROPELLED TRACKED VEHICLE TESTS

BEFORE-TRAFFIC RESIDUAL VANE SHEAR STRENGTH VS RUT DEPTH AFTER ONE PASS

SHEET 2 OF 2



SELF-PROPELLED TRACKED VEHICLE TESTS

BEFORE-TRAFFIC
RAMM HARDNESS NUMBER VS
RUT DEPTH AFTER ONE PASS

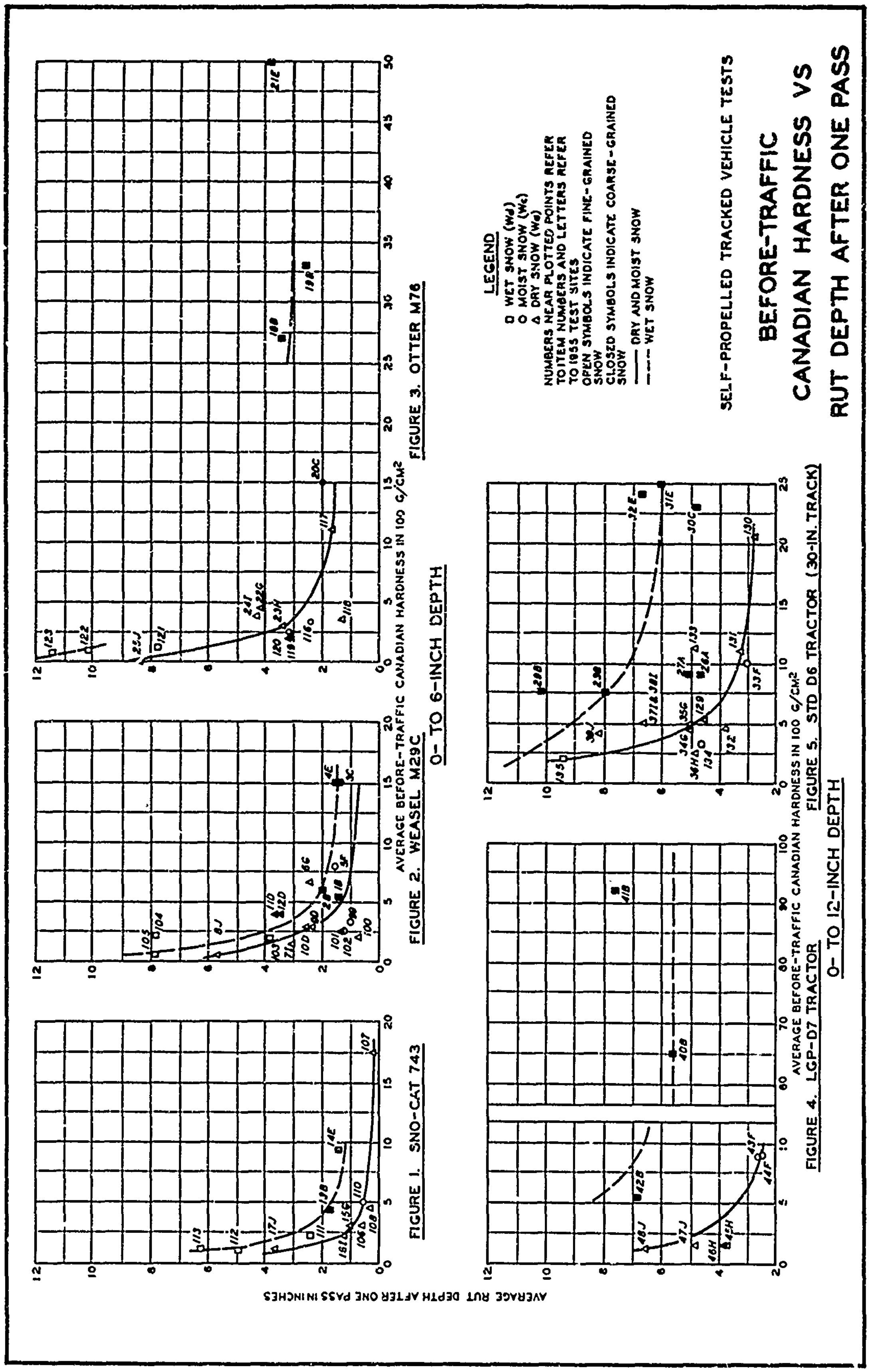

SELF-PROPELLED TRACKED VEHICLE TESTS
BEFORE-TRAFFIC
CANADIAN HARDNESS VS
RUT DEPTH AFTER ONE PASS
LEGEND
□ WET SNOW (Wd)
○ MOIST SNOW (Wc)
△ DRY SNOW (We)
NUMBERS NEAR PLOTTED POINTS REFER TO ITEM NUMBERS AND LETTERS REFER TO 1955 TEST SITES
OPEN SYMBOLS INDICATE FINE-GRAINED SNOW
CLOSED SYMBOLS INDICATE COARSE-GRAINED SNOW
DRY AND MOIST SNOW
WET SNOW
AVERAGE RUT DEPTH AFTER ONE PASS IN INCHES
AVERAGE BEFORE-TRAFFIC CANADIAN HARDNESS IN 100 G/CM²
FIGURE 1. SNO-CAT 743
FIGURE 2. WEASEL M29C
FIGURE 3. OTTER M76
0- TO 6-INCH DEPTH
FIGURE 4. LGP-D7 TRACTOR
FIGURE 5. STD D6 TRACTOR (30-IN. TRACK)
0- TO 12-INCH DEPTH

PLATE 11

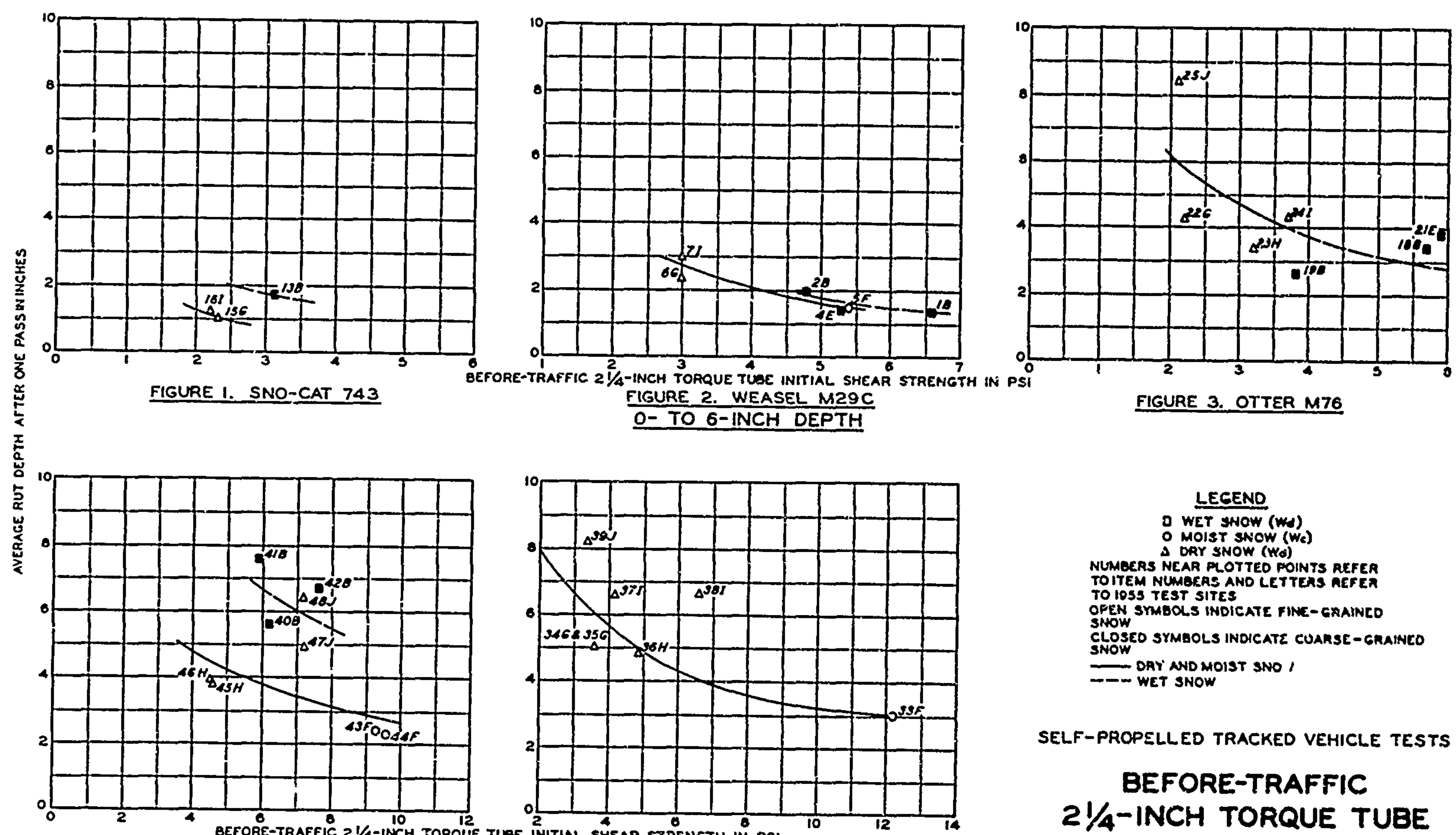


FIGURE 1. SNO-CAT 743

FIGURE 2. WEASEL M29C

FIGURE 3. OTTER M76

0- TO 6-INCH DEPTH

FIGURE 4. LGP-D7 TRACTOR

FIGURE 5. STD D8 TRACTOR (30-IN. TRACK)

0- TO 12-INCH DEPTH

SELF-PROPELLED TRACKED VEHICLE TESTS

BEFORE-TRAFFIC 2 1/4-INCH TORQUE TUBE INITIAL SHEAR STRENGTH (NOT-MOVED POSITION) VS RUT DEPTH AFTER ONE PASS

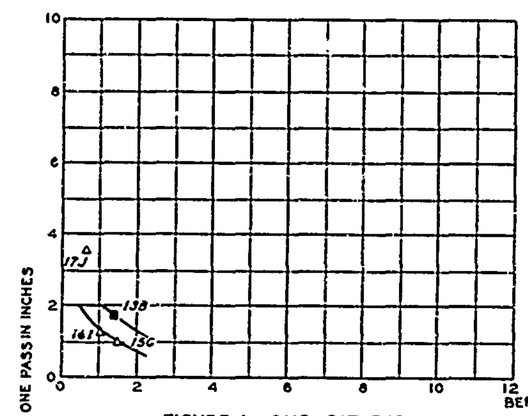


FIGURE 1. SNO-CAT 743

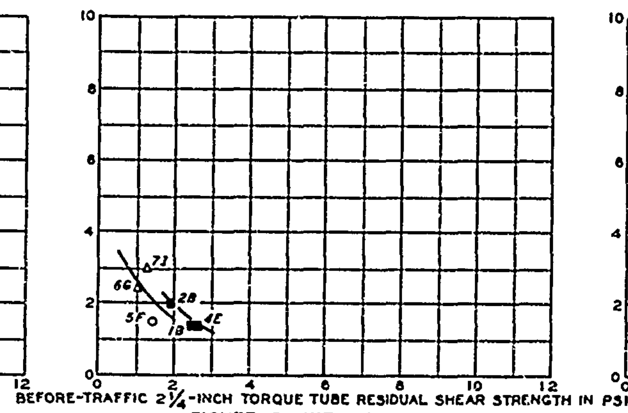


FIGURE 2. WEASEL M29C

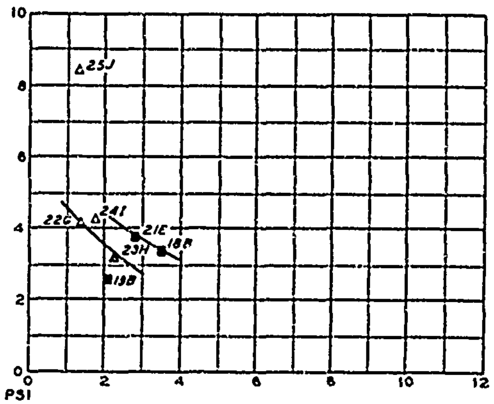


FIGURE 3. OTTER M76

0- TO 6-INCH DEPTH

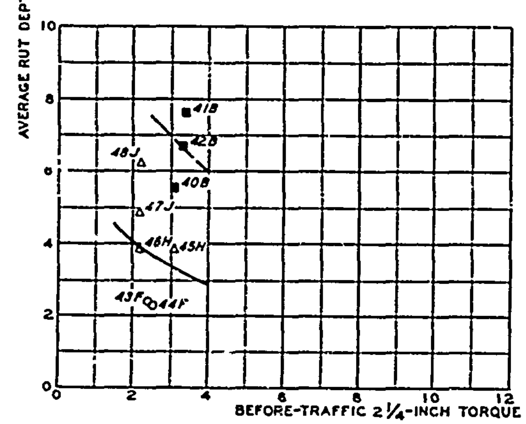


FIGURE 4. LGP-D7 TRACTOR

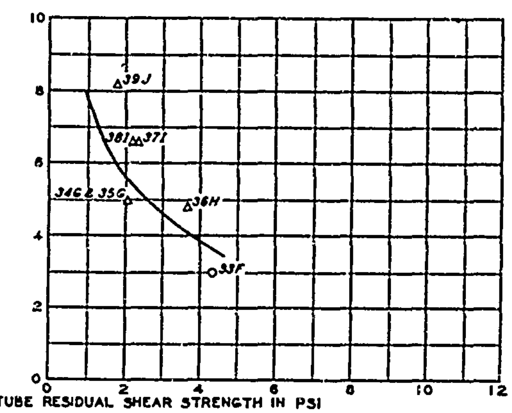


FIGURE 5. STD D6 TRACTOR (30-IN. TRACK)

0- TO 12-INCH DEPTH

LEGEND

□ WET SNOW (Wd)
○ MOIST SNOW (Wc)
△ DRY SNOW (Wa)

NUMBERS NEAR PLOTTED POINTS REFER TO ITEM NUMBERS AND LETTERS REFER TO 1955 TEST SITES
OPEN SYMBOLS INDICATE FINE-GRAINED SNOW
CLOSED SYMBOLS INDICATE COARSE-GRAINED SNOW
—— DRY AND MOIST SNOW
– – – WET SNOW

SELF-PROPELLED TRACKED VEHICLE TESTS

BEFORE-TRAFFIC 2¼-INCH TORQUE TUBE RESIDUAL SHEAR STRENGTH (NOT-MOVED POSITION) VS RUT DEPTH AFTER ONE PASS

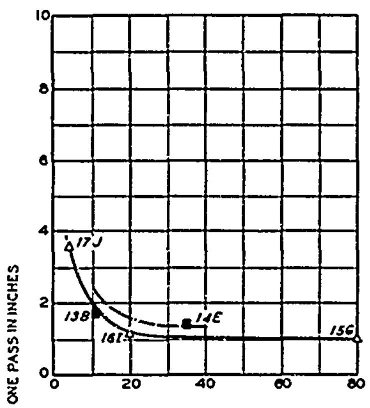


FIGURE 1. SNO-CAT 743

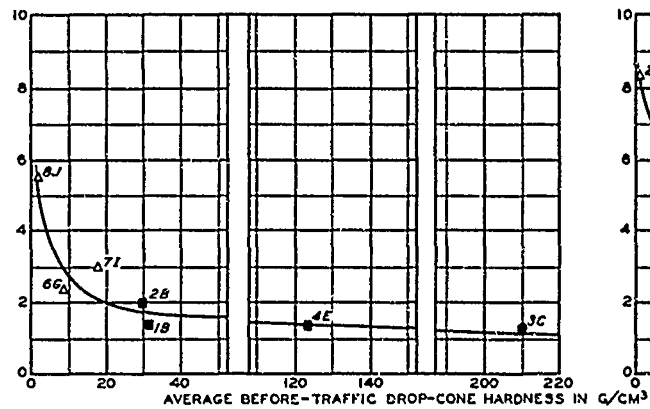


FIGURE 2. WEASEL M29C

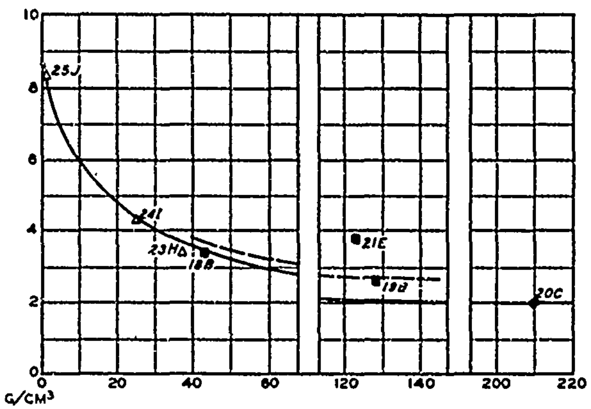


FIGURE 3. OTTER M76

0- TO 6-INCH DEPTH

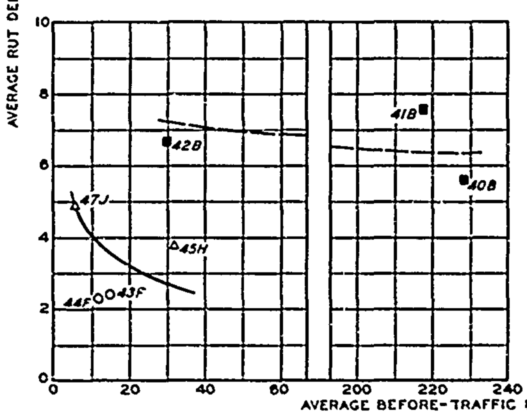


FIGURE 4. LGP-D7 TRACTOR

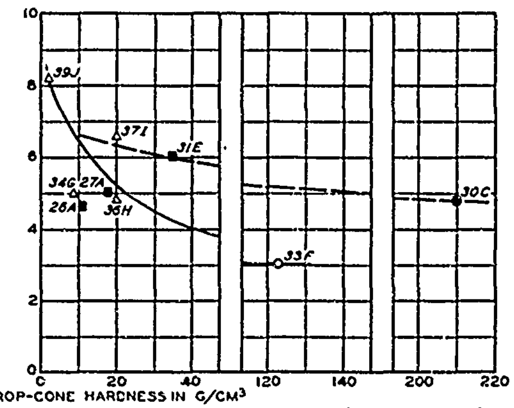


FIGURE 5. STD D6 TRACTOR (30-IN. TRACK)

0- TO 12-INCH DEPTH

LEGEND

□ WET SNOW (W_d)
○ MOIST SNOW (W_c)
△ DRY SNOW (W_a)

NUMBERS NEAR PLOTTED POINTS REFER TO ITEM NUMBERS AND LETTERS REFER TO 1955 TEST SITES

OPEN SYMBOLS INDICATE FINE-GRAINED SNOW

CLOSED SYMBOLS INDICATE COARSE-GRAINED SNOW

——— DRY AND MOIST SNOW

– – – WET SNOW

SELF-PROPELLED TRACKED VEHICLE TESTS

BEFORE-TRAFFIC DROP-CONE HARDNESS VS RUT DEPTH AFTER ONE PASS

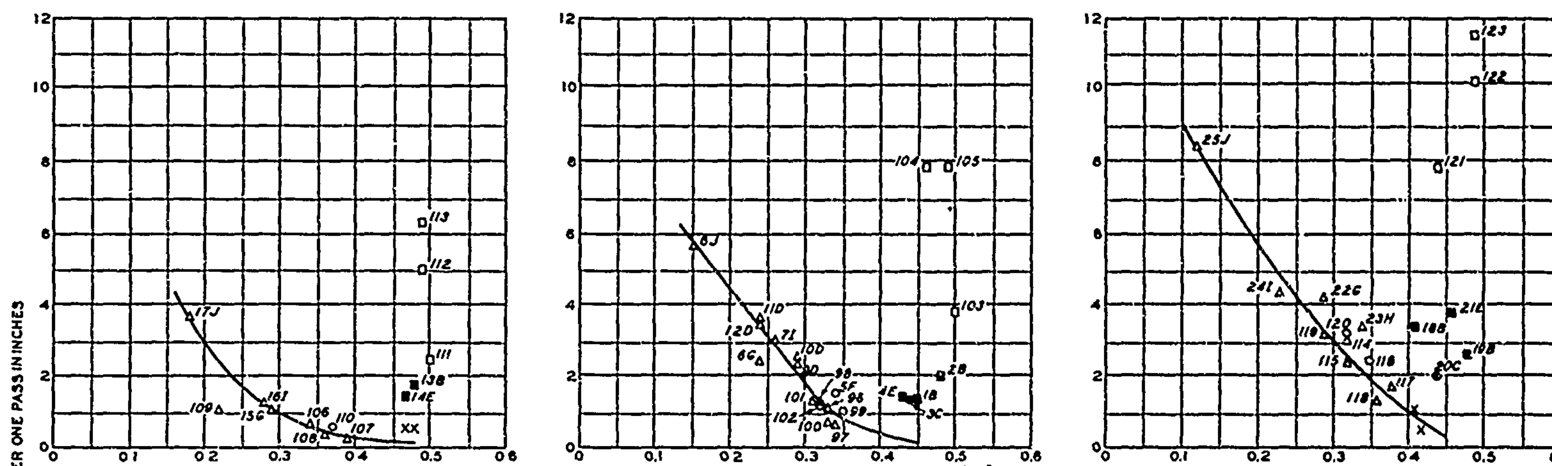


FIGURE 1. SNO-CAT 743

FIGURE 2. WEASEL M29C

FIGURE 3. OTTER M76

0- TO 6-INCH DEPTH

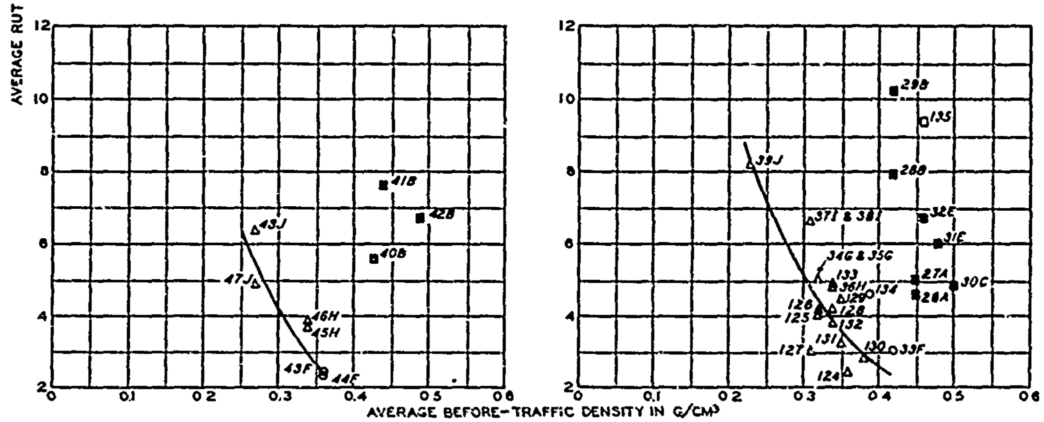


FIGURE 4. LGP-D7 TRACTOR

FIGURE 5 STD D6 TRACTOR (30-IN. TRACK)

0- TO 12-INCH DEPTH

LEGEND

GREENLAND-1955 & 1957	GREENLAND-1954
□ WET SNOW (Wd)	X DRY SNOW (Db)
O MOIST SNOW (Wc)	
Δ DRY SNOW (Wa)	

NUMBERS NEAR PLOTTED POINTS REFER TO ITEM NUMBERS AND LETTERS REFER TO 1955 TEST SITES
OPEN SYMBOLS INDICATE FINE-GRAINED SNOW
CLOSED SYMBOLS INDICATE COARSE-GRAINED SNOW
—— DRY AND MOIST SNOW

SELF-PROPELLED TRACKED VEHICLE TESTS

BEFORE-TRAFFIC DENSITY VS RUT DEPTH AFTER ONE PASS

SHEET 1 OF 2

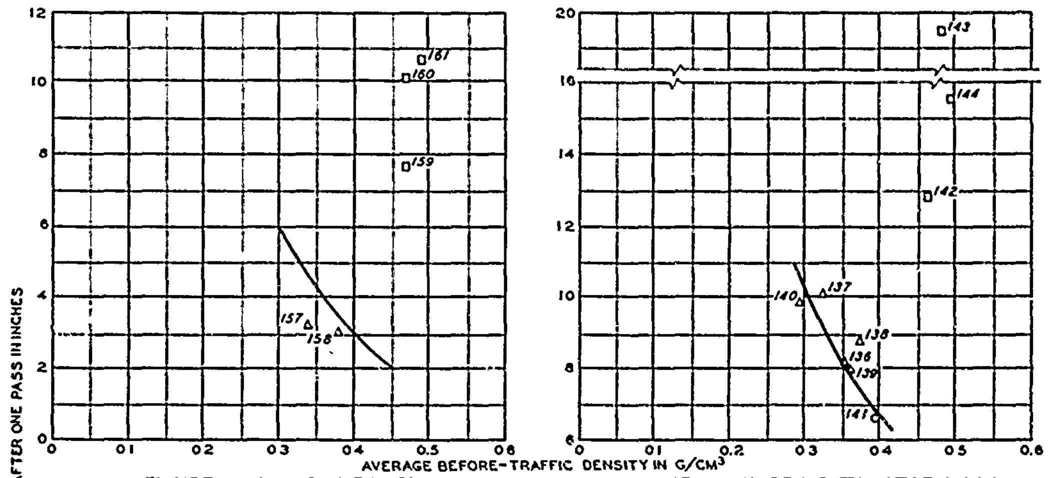


FIGURE 6. LGP-D8 TRACTOR

FIGURE 7. HI-SPEED TRACTOR M5A4

0- TO 12-INCH DEPTH

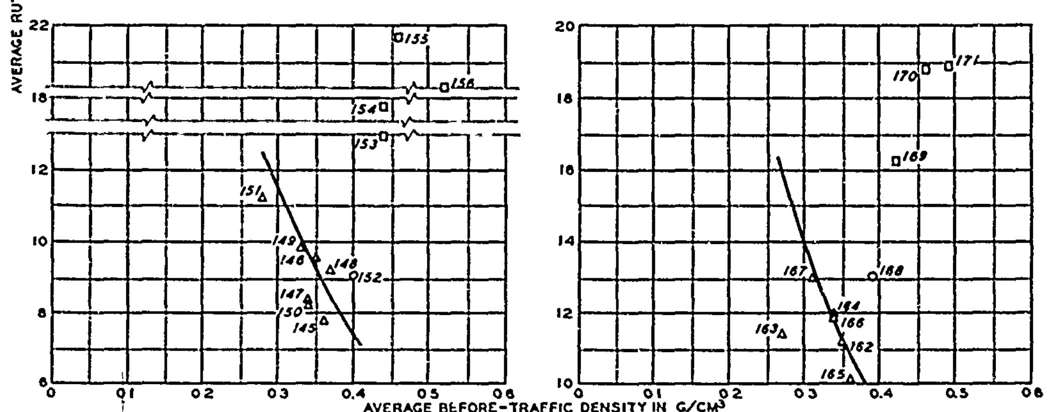


FIGURE 8 HI-SPEED TRACTOR M4

FIGURE 9. MEDIUM TANK M 48

0- TO 12-INCH DEPTH

LEGEND

□ WET SNOW (W_d)
○ MOIST SNOW (W_c)
△ DRY SNOW (W_a)

NUMBERS NEAR PLOTTED POINTS REFER TO ITEM NUMBERS AND LETTERS REFER TO 1955 TEST SITES

OPEN SYMBOLS INDICATE FINE-GRAINED SNOW

CLOSED SYMBOLS INDICATE COARSE-GRAINED SNOW

—— DRY AND MOIST SNOW

SELF-PROPELLED TRACKED VEHICLE TESTS

BEFORE-TRAFFIC DENSITY VS RUT DEPTH AFTER ONE PASS

SHEET 2 OF 2

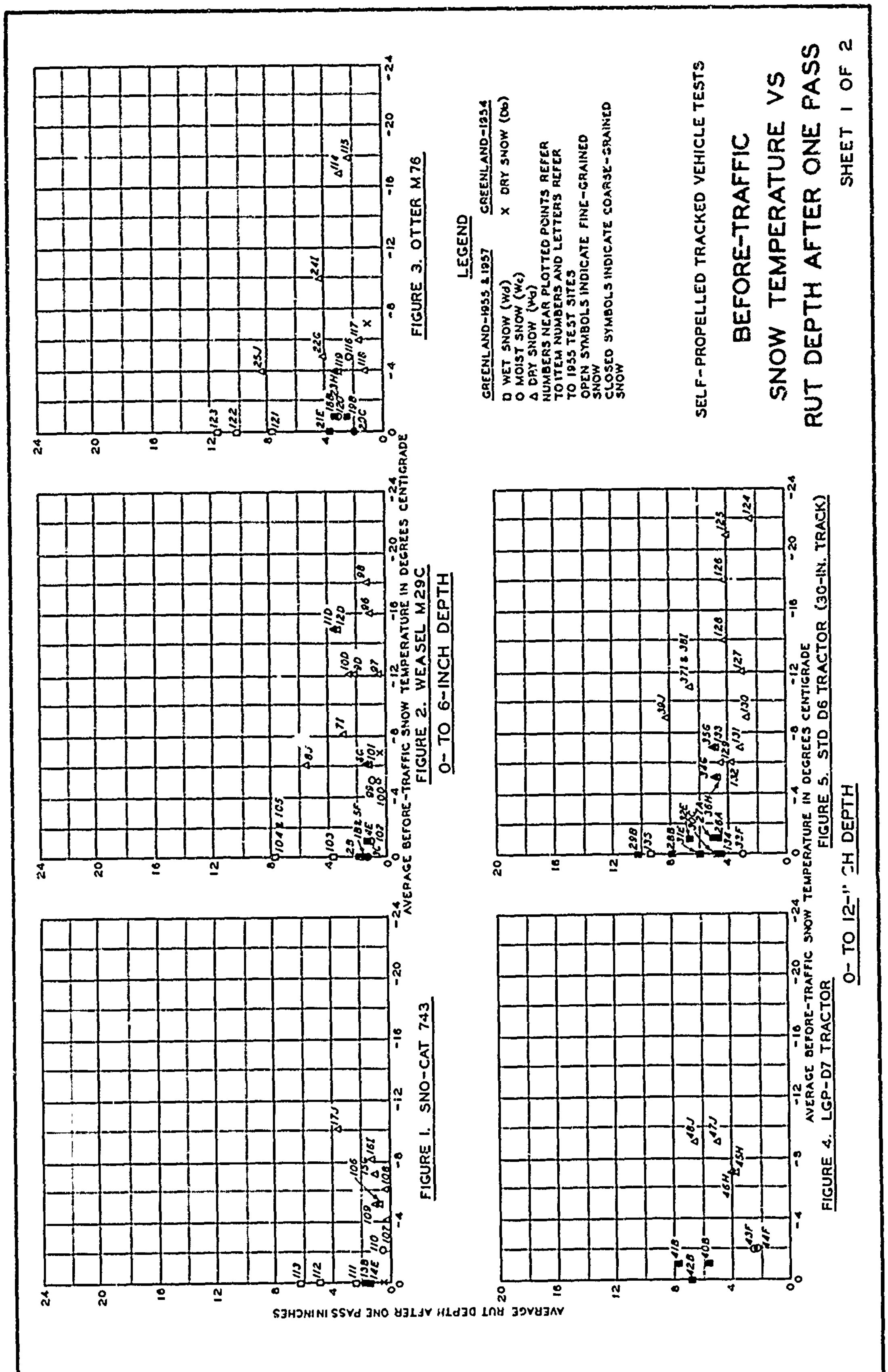

SELF-PROPELLED TRACKED VEHICLE TESTS
BEFORE-TRAFFIC
SNOW TEMPERATURE VS
RUT DEPTH AFTER ONE PASS
SHEET 1 OF 2
LEGEND
GREENLAND-1955 & 1957
□ WET SNOW (Wd)
○ MOIST SNOW (Wc)
△ DRY SNOW (Wd)
GREENLAND-1954
X DRY SNOW (Db)
NUMBERS NEAR PLOTTED POINTS REFER TO ITEM NUMBERS AND LETTERS REFER TO 1955 TEST SITES
OPEN SYMBOLS INDICATE FINE-GRAINED SNOW
CLOSED SYMBOLS INDICATE COARSE-GRAINED SNOW
FIGURE 1. SNO-CAT 743
FIGURE 2. WEASEL M29C
FIGURE 3. OTTER M76
0- TO 6-INCH DEPTH
FIGURE 4. LGP-D7 TRACTOR
FIGURE 5. STD D6 TRACTOR (30-IN. TRACK)
0- TO 12-INCH DEPTH
AVERAGE RUT DEPTH AFTER ONE PASS IN INCHES
AVERAGE BEFORE-TRAFFIC SNOW TEMPERATURE IN DEGREES CENTIGRADE

PLATE 16

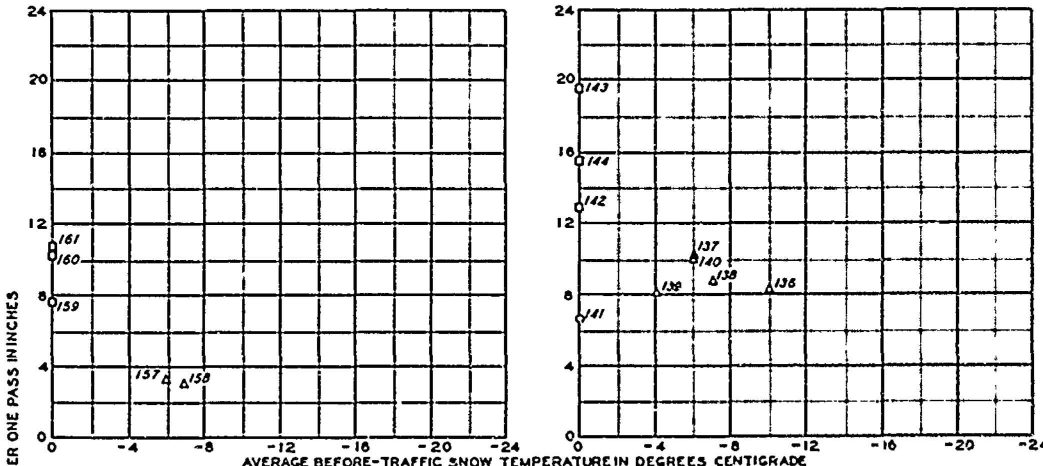


FIGURE 6. LGP-D8 TRACTOR

FIGURE 7. HI-SPEED TRACTOR M5A4

0- TO 12-INCH DEPTH

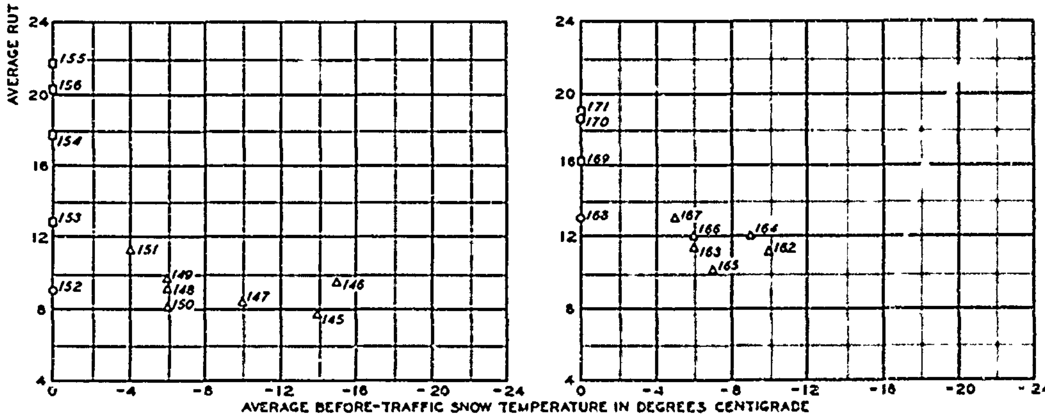


FIGURE 8 HI-SPEED TRACTOR M4

FIGURE 9 MEDIUM TANK M48

0- TO 12-INCH DEPTH

LEGEND

□ WET SNOW (Wd)
○ MOIST SNOW (Wc)
△ DRY SNOW (Wa)

NUMBERS NEAR PLOTTED POINTS REFER TO ITEM NUMBERS AND LETTERS REFER TO 1955 TEST SITES

OPEN SYMBOLS INDICATE FINE-GRAINED SNOW

CLOSED SYMBOLS INDICATE COARSE-GRAINED SNOW

SELF-PROPELLED TRACKED VEHICLE TESTS

BEFORE-TRAFFIC SNOW TEMPERATURE VS RUT DEPTH AFTER ONE PASS

SHEET 2 OF 2

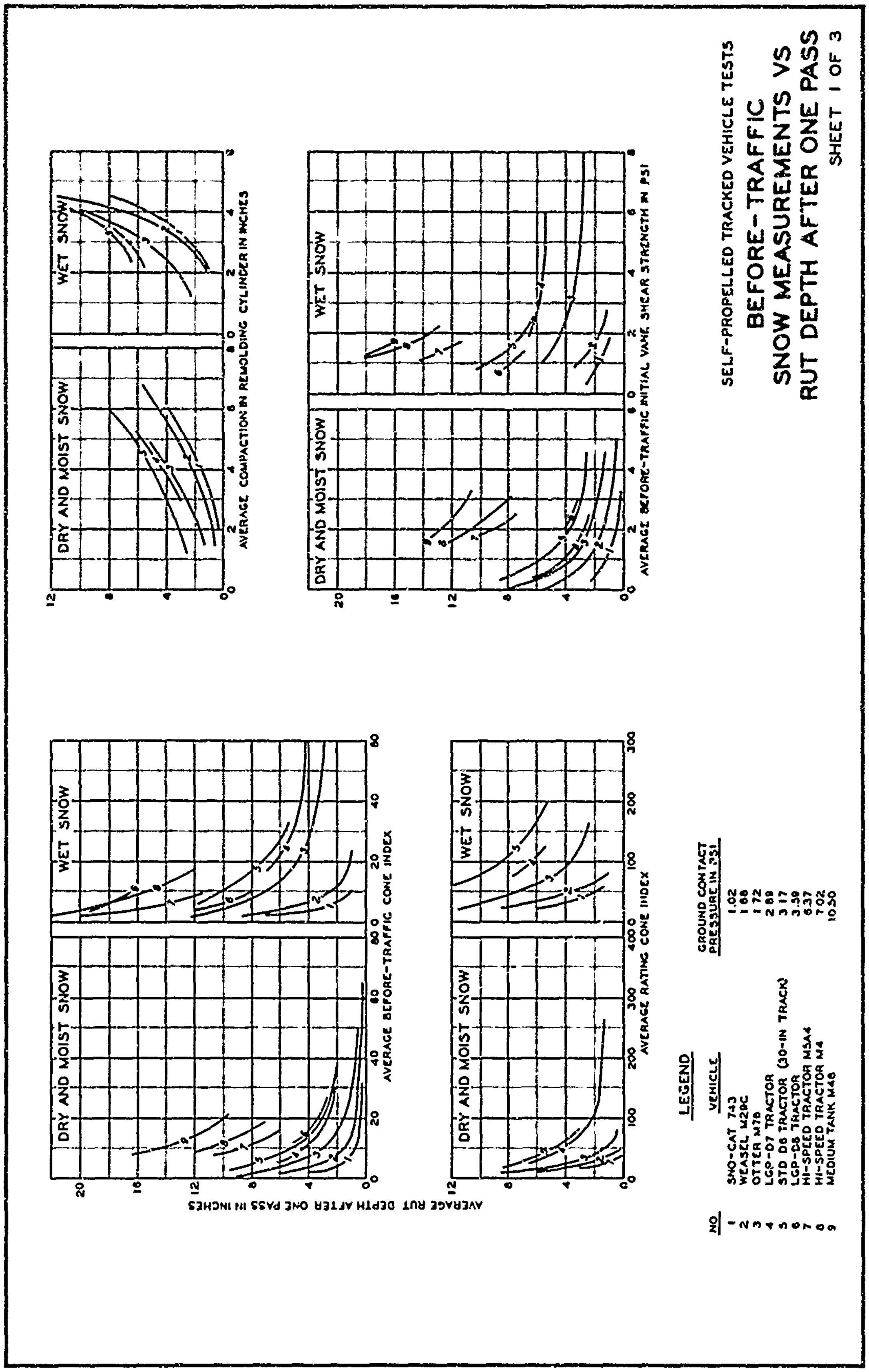
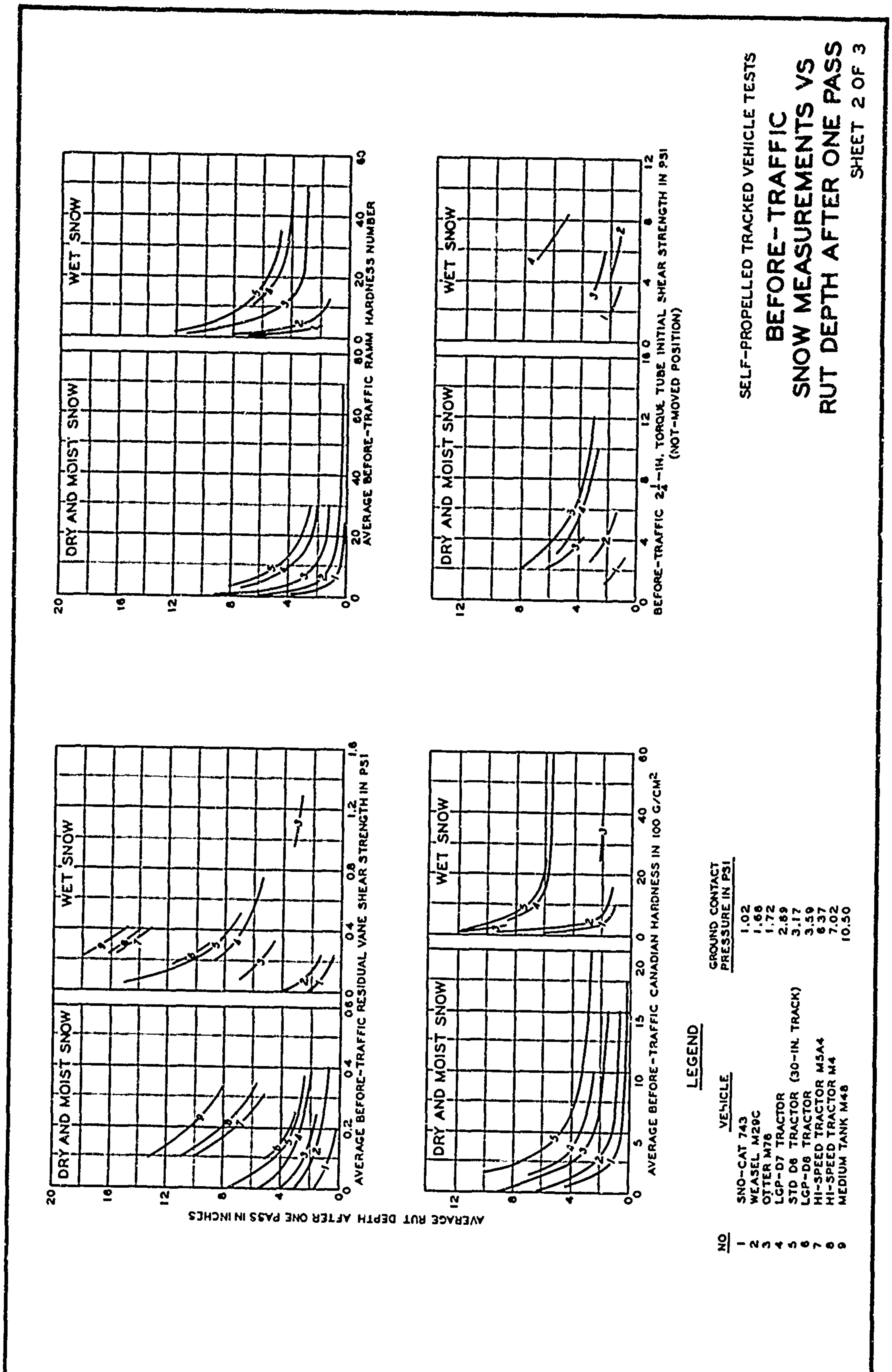
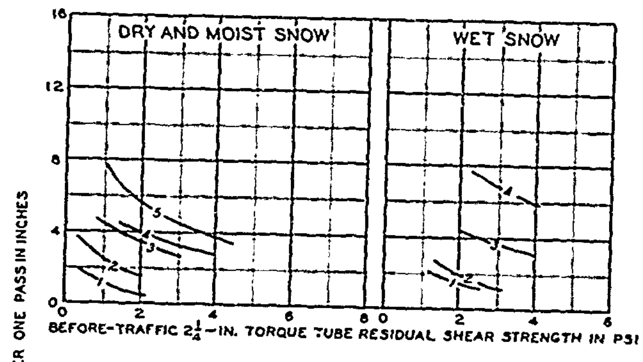
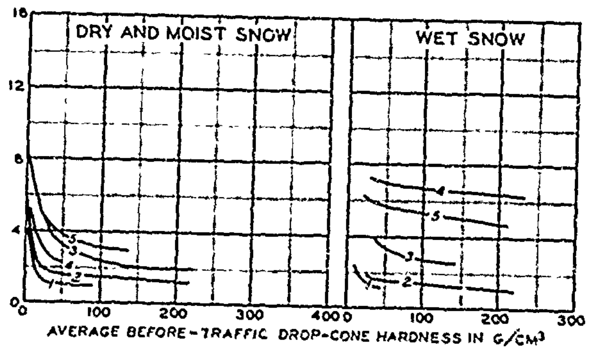
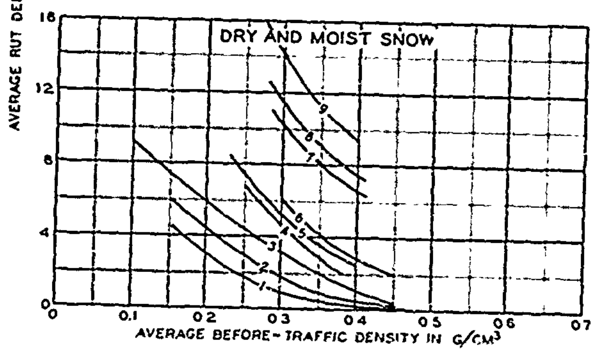

SELF-PROPELLED TRACKED VEHICLE TESTS
BEFORE-TRAFFIC
SNOW MEASUREMENTS VS
RUT DEPTH AFTER ONE PASS
SHEET 1 OF 3
DRY AND MOIST SNOW
WET SNOW
AVERAGE RUT DEPTH AFTER ONE PASS IN INCHES
AVERAGE BEFORE-TRAFFIC CONE INDEX
AVERAGE RATING CONE INDEX
AVERAGE COMPACTION IN REMOLDING CYLINDER IN INCHES
AVERAGE BEFORE-TRAFFIC INITIAL VANE SHEAR STRENGTH IN PSI
LEGEND
NO VEHICLE GROUND CONTACT PRESSURE IN PSI
1 SNO-CAT 743 1.02
2 WEASEL M29C 1.68
3 OTTER M76 1.72
4 LGP-D7 TRACTOR 2.89
5 STD D6 TRACTOR (30-IN TRACK) 3.17
6 LGP-D8 TRACTOR 3.59
7 HI-SPEED TRACTOR M5A4 6.37
8 HI-SPEED TRACTOR M4 7.02
9 MEDIUM TANK M46 10.50

PLATE 17


SELF-PROPELLED TRACKED VEHICLE TESTS
BEFORE-TRAFFIC
SNOW MEASUREMENTS VS
RUT DEPTH AFTER ONE PASS
SHEET 2 OF 3
DRY AND MOIST SNOW
WET SNOW
AVERAGE RUT DEPTH AFTER ONE PASS IN INCHES
AVERAGE BEFORE-TRAFFIC RAMM HARDNESS NUMBER
BEFORE-TRAFFIC 2¼-IN. TORQUE TUBE INITIAL SHEAR STRENGTH IN PSI
(NOT-MOVED POSITION)
AVERAGE BEFORE-TRAFFIC RESIDUAL VANE SHEAR STRENGTH IN PSI
AVERAGE BEFORE-TRAFFIC CANADIAN HARDNESS IN 100 G/CM²
LEGEND
NO
VEHICLE
GROUND CONTACT PRESSURE IN PSI
1 SNO-CAT 743 1.02
2 WEASEL M29C 1.66
3 OTTER M76 1.72
4 LGP-D7 TRACTOR 2.89
5 STD D8 TRACTOR (30-IN. TRACK) 3.17
6 LGP-D8 TRACTOR 3.59
7 HI-SPEED TRACTOR M5A4 6.37
8 HI-SPEED TRACTOR M4 7.02
9 MEDIUM TANK M46 10.50







LEGEND

NO	VEHICLE	GROUND CONTACT PRESSURE IN PSI
1	SNO-CAT 743	1.02
2	WEASEL M29C	1.68
3	OTTER M76	1.72
4	LGP-D7 TRACTOR	2.89
5	STD D8 TRACTOR (30-IN. TRACK)	3.17
6	LGP-D8 TRACTOR	3.59
7	HI-SPEED TRACTOR M5A4	6.37
8	HI-SPEED TRACTOR M4	7.02
9	MEDIUM TANK M48	10.50

SELF-PROPELLED TRACKED VEHICLE TESTS

BEFORE-TRAFFIC SNOW MEASUREMENTS VS RUT DEPTH AFTER ONE PASS

SHEET 3 OF 3

PLATE 17

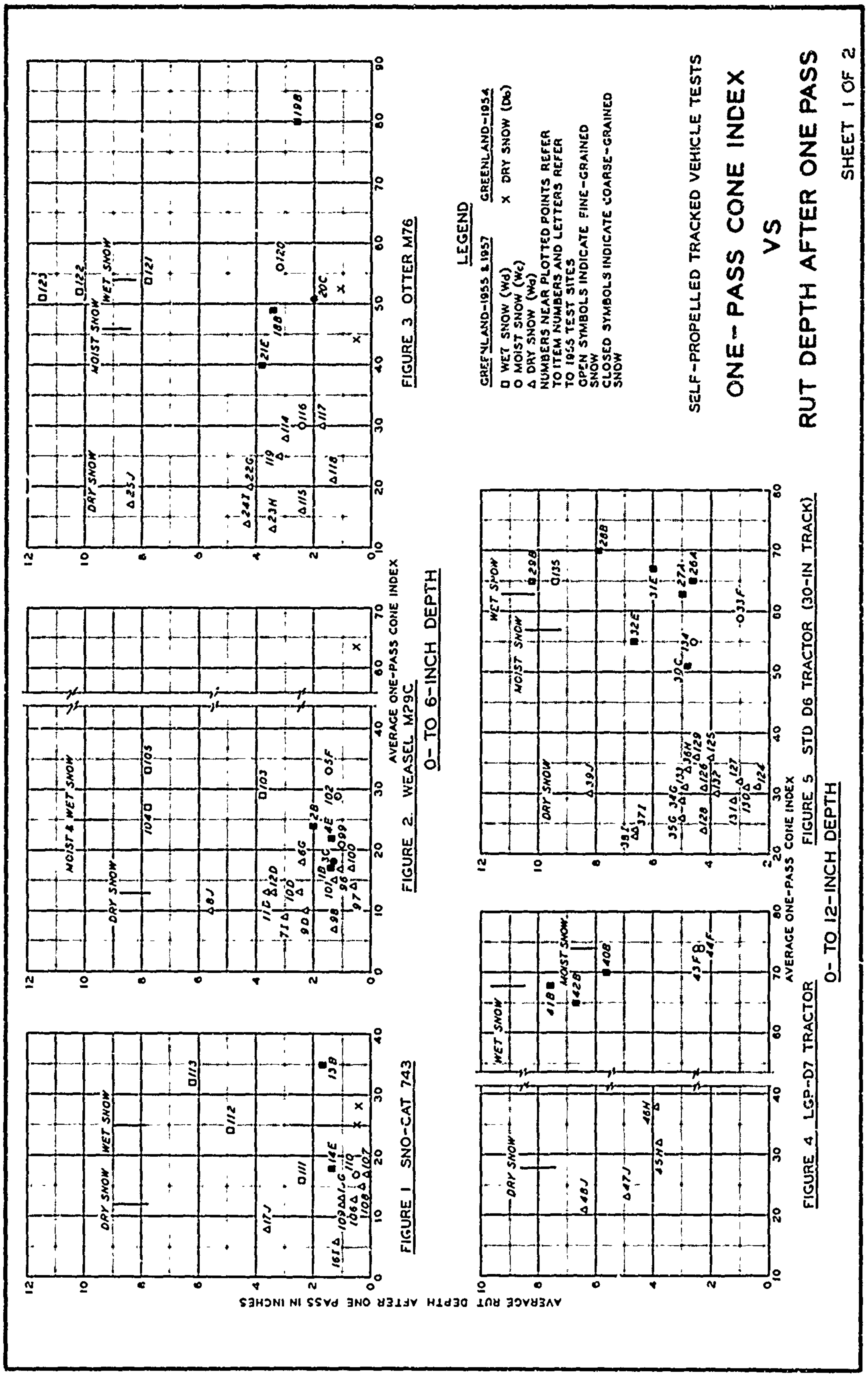

AVERAGE RUT DEPTH AFTER ONE PASS IN INCHES
AVERAGE ONE-PASS CONE INDEX
FIGURE 1 SNO-CAT 743
FIGURE 2 WEASEL M29C
0- TO 6-INCH DEPTH
FIGURE 3 OTTER M76
FIGURE 4 LGP-D7 TRACTOR
FIGURE 5 STD D6 TRACTOR (30-IN TRACK)
0- TO 12-INCH DEPTH
DRY SNOW
MOIST SNOW
WET SNOW
MOIST & WET SNOW
LEGEND
GREENLAND-1955 & 1957
□ WET SNOW (Wd)
O MOIST SNOW (Wc)
Δ DRY SNOW (Wd)
GREENLAND-1954
X DRY SNOW (Dc)
NUMBERS NEAR PLOTTED POINTS REFER TO ITEM NUMBERS AND LETTERS REFER TO 1955 TEST SITES
OPEN SYMBOLS INDICATE FINE-GRAINED SNOW
CLOSED SYMBOLS INDICATE COARSE-GRAINED SNOW
SELF-PROPELLED TRACKED VEHICLE TESTS
ONE-PASS CONE INDEX
VS
RUT DEPTH AFTER ONE PASS
SHEET 1 OF 2

PLATE 18

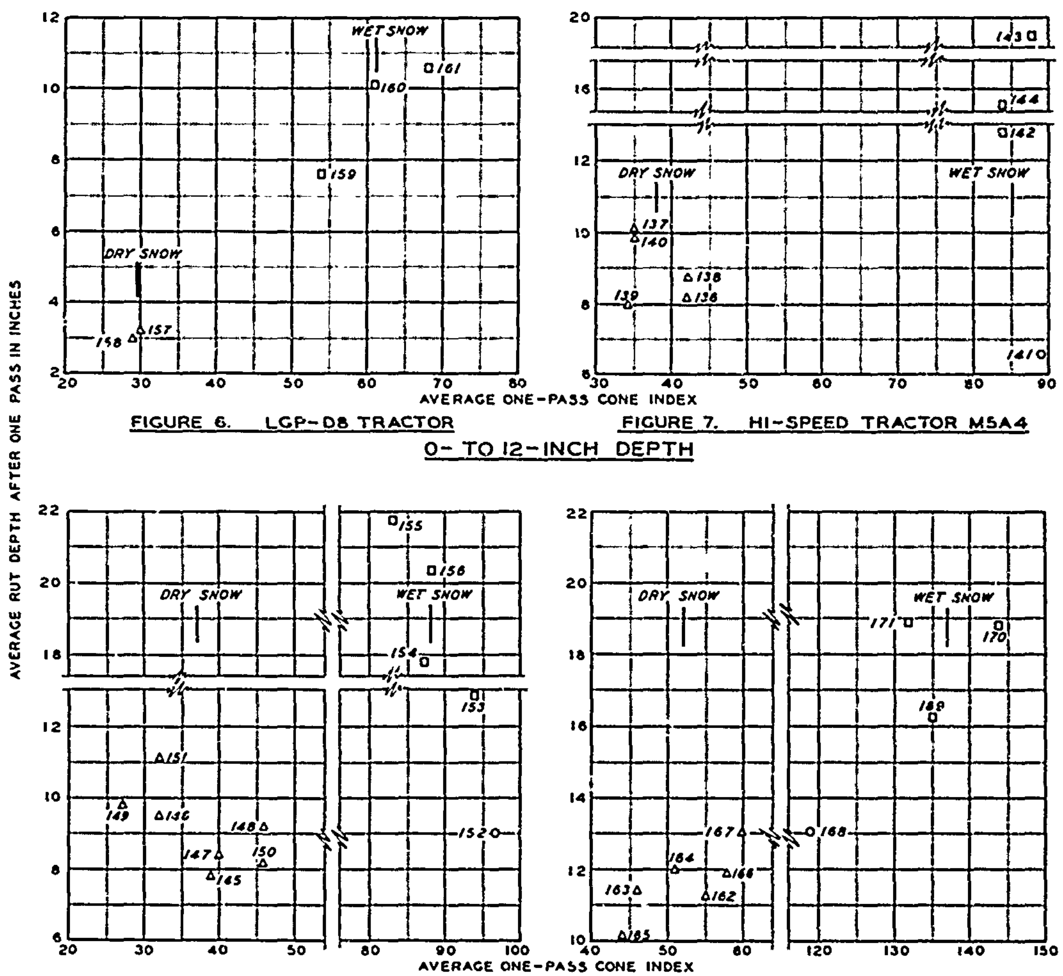


FIGURE 6. LGP-D8 TRACTOR

FIGURE 7. HI-SPEED TRACTOR M5A4

0- TO 12-INCH DEPTH

FIGURE 8. HI-SPEED TRACTOR M4

FIGURE 9. MEDIUM TANK M48

0- TO 12-INCH DEPTH

LEGEND

□ WET SNOW (Wd)
○ MOIST SNOW (Wc)
△ DRY SNOW (Wo)
NUMBERS NEAR PLOTTED POINTS REFER TO ITEM NUMBERS AND LETTERS REFER TO 1955 TEST SITES
OPEN SYMBOLS INDICATE FINE-GRAINED SNOW
CLOSED SYMBOLS INDICATE COARSE-GRAINED SNOW

SELF-PROPELLED TRACKED VEHICLE TESTS

ONE-PASS CONE INDEX
VS
RUT DEPTH AFTER ONE PASS

SHEET 2 OF 2

AVERAGE RUT DEPTH AFTER ONE PASS IN INCHES

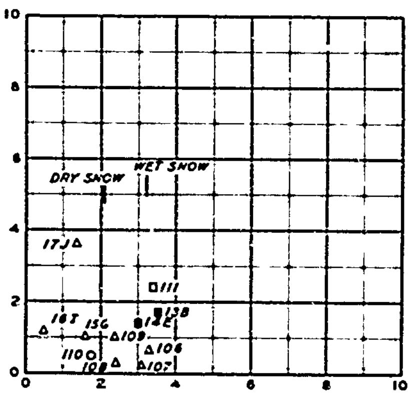
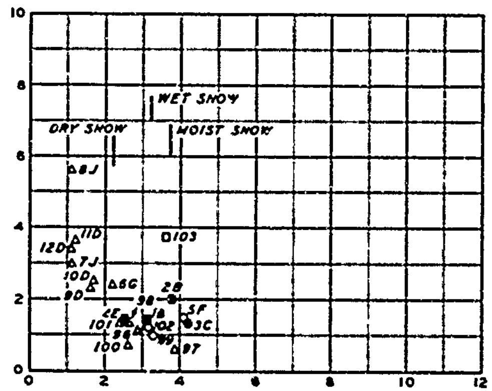


FIGURE 1 SNO-CAT 743



AVERAGE ONE-PASS INITIAL VANE SHEAR STRENGTH IN PSI

FIGURE 2 WEASEL M29C

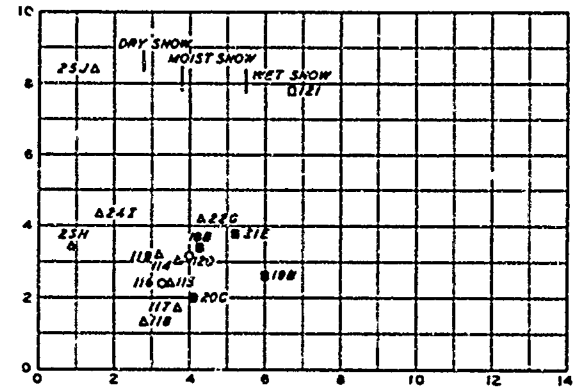


FIGURE 3 OTTER M76

0- TO 6-INCH DEPTH

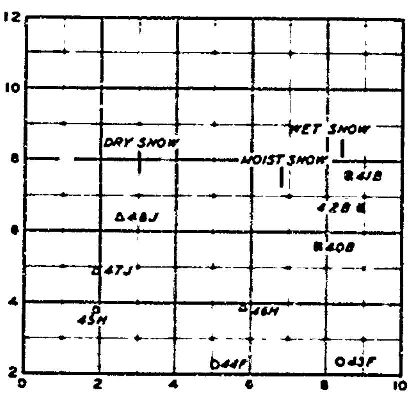
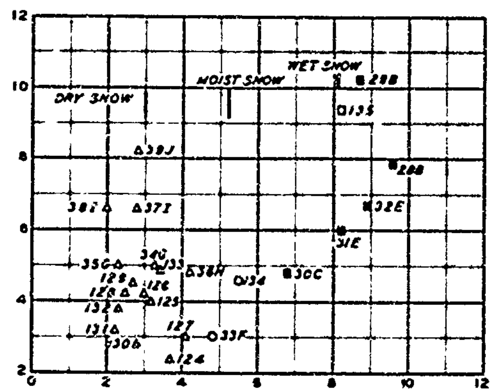


FIGURE 4 LGP-D7 TRACTOR



AVERAGE ONE-PASS INITIAL VANE SHEAR STRENGTH IN PSI

FIGURE 5 STD D6 TRACTOR (30-IN. TRACK)

0- TO 12-INCH DEPTH

LEGEND

□ WET SNOW (W_d)
○ MOIST SNOW (W_c)
△ DRY SNOW (W_a)

NUMBERS NEAR PLOTTED POINTS REFER TO ITEM NUMBERS AND LETTERS REFER TO 1955 TEST SITES

OPEN SYMBOLS INDICATE FINE-GRAINED SNOW

CLOSED SYMBOLS INDICATE COARSE-GRAINED SNOW

SELF-PROPELLED TRACKED VEHICLE TESTS

ONE-PASS INITIAL VANE SHEAR STRENGTH VS RUT DEPTH AFTER ONE PASS

SHEET 1 OF 2

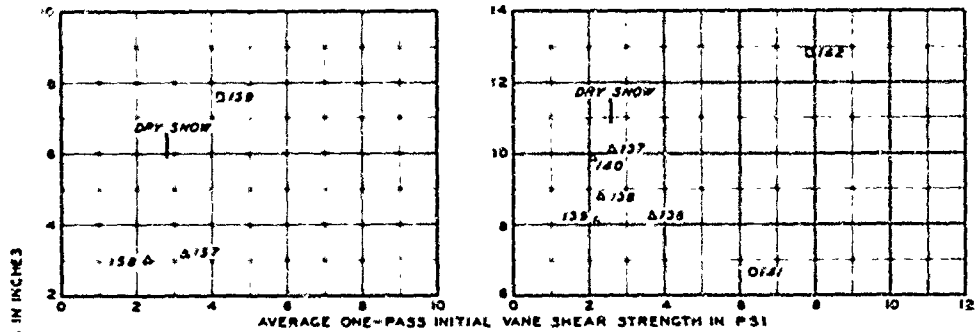


FIGURE 6 LGP-D8 TRACTOR

FIGURE 7 HI-SPEED TRACTOR M5A4

0- TO 12-INCH DEPTH

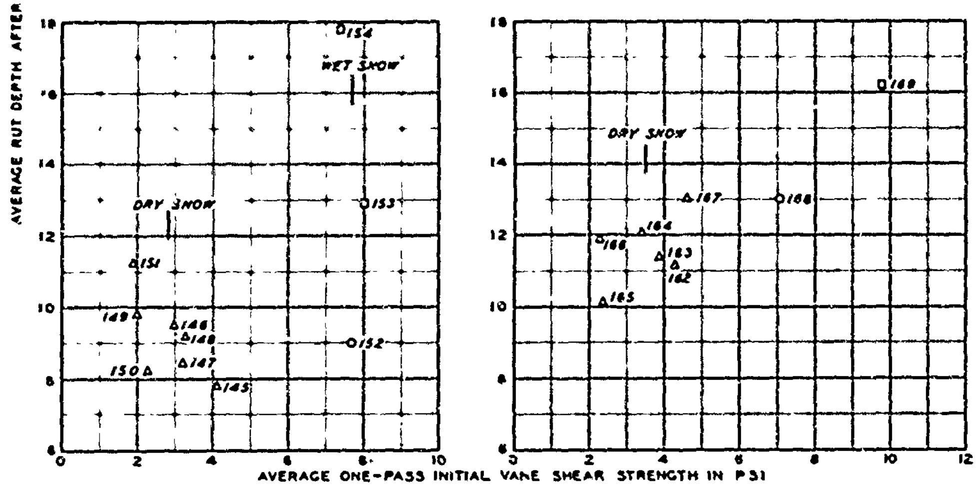


FIGURE 8 HI-SPEED TRACTOR M4

FIGURE 9 MEDIUM TANK M48

0- TO 12-INCH DEPTH

LEGEND

□ WET SNOW (Wd)
○ MOIST SNOW (Wc)
△ DRY SNOW (We)
NUMBERS NEAR PLOTTED POINTS REFER TO ITEM NUMBERS AND LETTERS REFER TO 1955 TEST SITES
OPEN SYMBOLS INDICATE FINE-GRAINED SNOW
CLOSED SYMBOLS INDICATE COARSE-GRAINED SNOW

SELF-PROPELLED TRACKED VEHICLE TESTS

ONE-PASS INITIAL VANE SHEAR STRENGTH VS RUT DEPTH AFTER ONE PASS

SHEET 2 OF 2

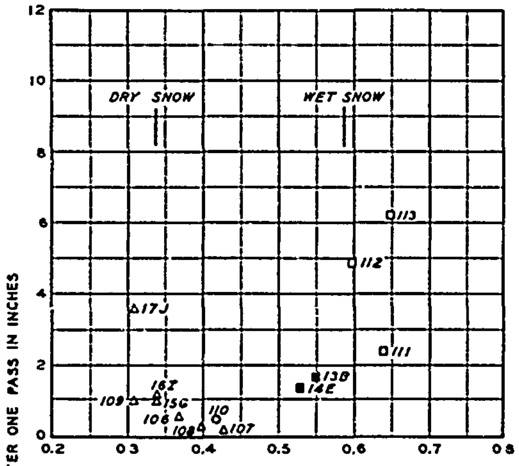


FIGURE 1. SNOW - CAT 743

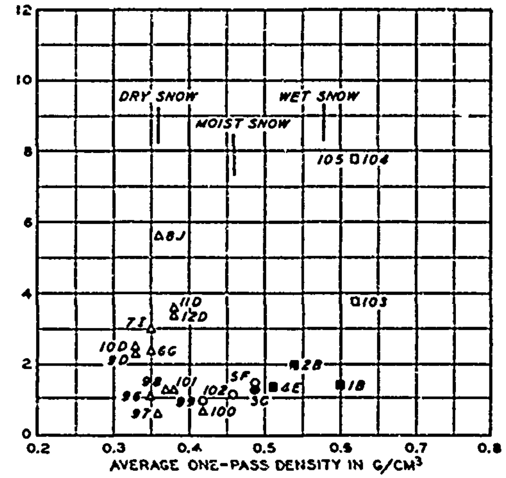


FIGURE 2. WEASEL M 29 C

0- TO 6-INCH DEPTH

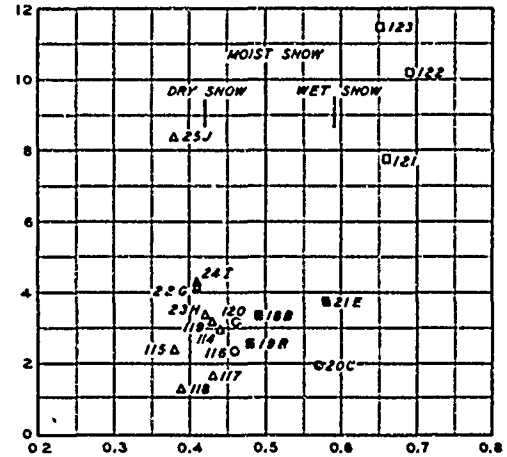


FIGURE 3. OTTER M 76

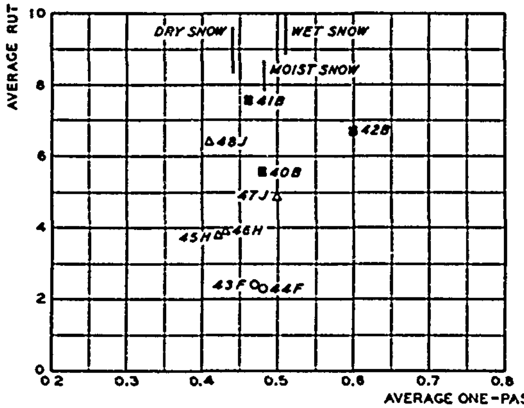
LEGEND

□ WET SNOW (W_d)
○ MOIST SNOW (W_c)
△ DRY SNOW (W_a)

NUMBERS NEAR PLOTTED POINTS REFER TO ITEM NUMBERS AND LETTERS REFER TO 1955 TEST SITES

OPEN SYMBOLS INDICATE FINE-GRAINED SNOW

CLOSED SYMBOLS INDICATE COARSE-GRAINED SNOW



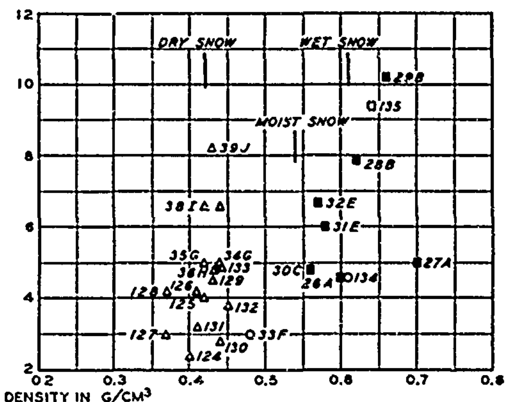


FIGURE 4. LGP-D7 TRACTOR

FIGURE 5. STD D8 TRACTOR (30-IN. TRACK)

0- TO 12- INCH DEPTH

SELF - PROPELLED TRACKED VEHICLE TESTS

ONE-PASS DENSITY VS RUT DEPTH AFTER ONE PASS

SHEET 1 OF 2

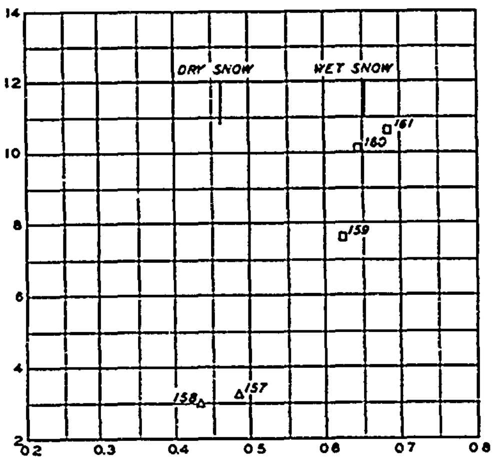


FIGURE 6. LGP-D8 TRACTOR

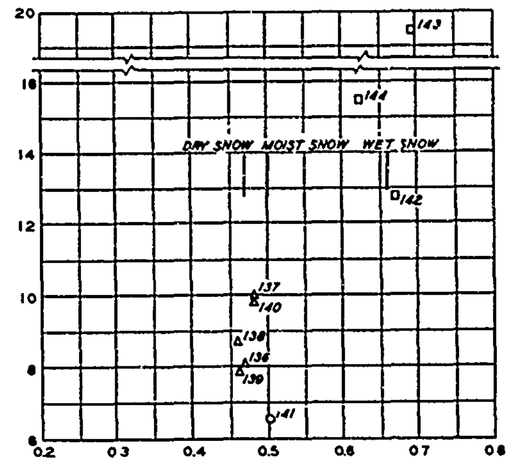


FIGURE 7. HI-SPEED TRACTOR M5A4

AVERAGE RUT DEPTH AFTER ONE PASS IN INCHES

AVERAGE ONE-PASS DENSITY IN G/CM³

0- TO 12-INCH DEPTH

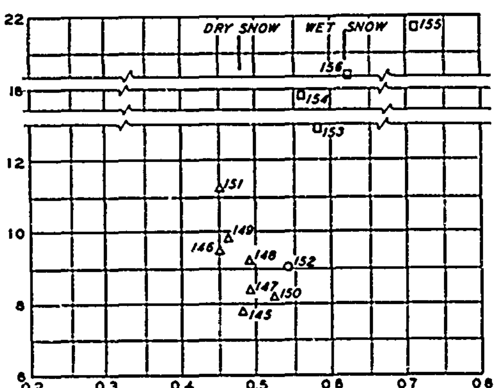


FIGURE 8. HI-SPEED TRACTOR M4

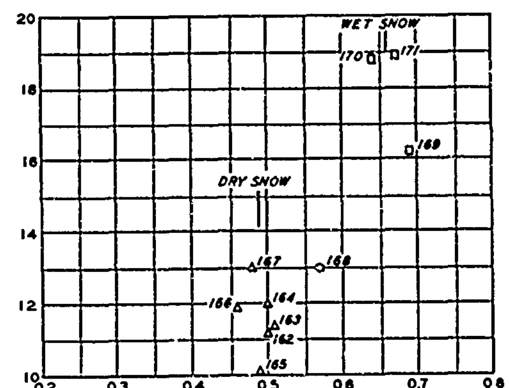


FIGURE 9. MEDIUM TANK M48

AVERAGE ONE-PASS DENSITY IN G/CM³

0- TO 12-INCH DEPTH

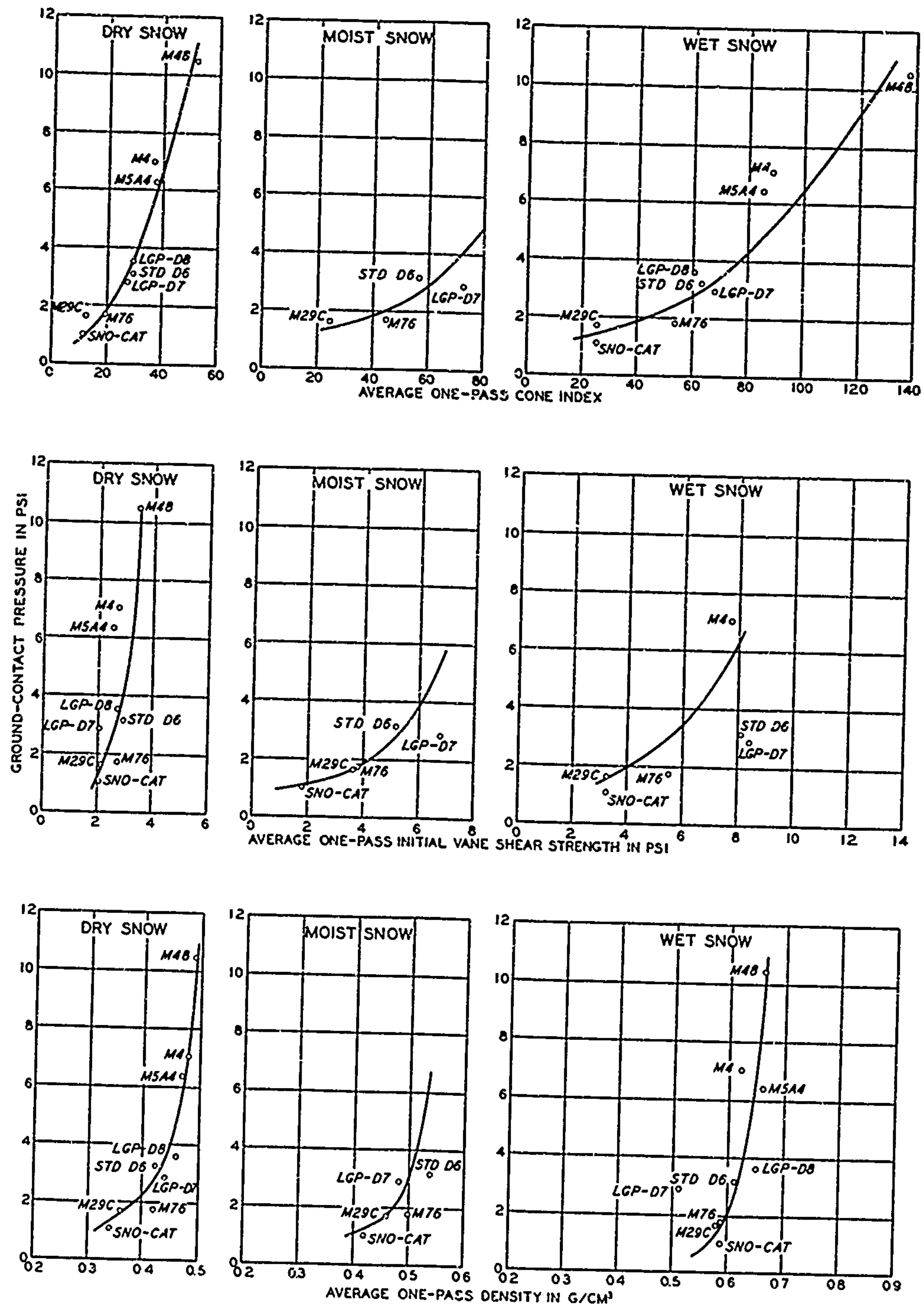
LEGEND

□ WET SNOW (Wd)
○ MOIST SNOW (Wc)
△ DRY SNOW (Wa)
NUMBERS NEAR PLOTTED POINTS REFER TO ITEM NUMBERS AND LETTERS REFER TO 1955 TEST SITES
OPEN SYMBOLS INDICATE FINE-GRAINED SNOW
CLOSED SYMBOLS INDICATE COARSE-GRAINED SNOW

SELF - PROPELLED TRACKED VEHICLE TESTS

ONE-PASS DENSITY VS RUT DEPTH AFTER ONE PASS

SHEET 2 OF 2



SELF-PROPELLED TRACKED VEHICLE TESTS

ONE-PASS
SNOW MEASUREMENTS VS
GROUND-CONTACT PRESSURE

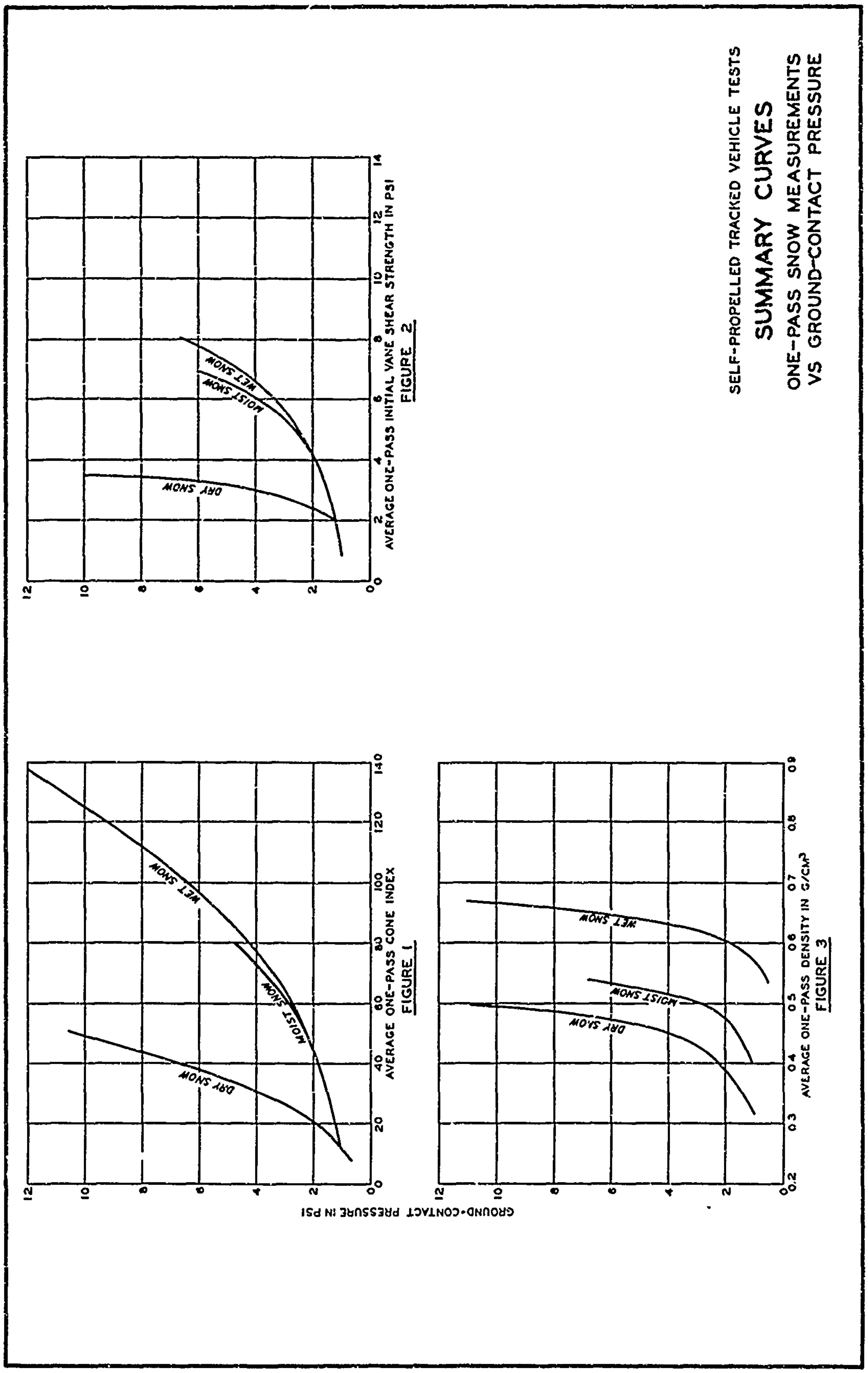

SELF-PROPELLED TRACKED VEHICLE TESTS
SUMMARY CURVES
ONE-PASS SNOW MEASUREMENTS VS GROUND-CONTACT PRESSURE
GROUND-CONTACT PRESSURE IN PSI
AVERAGE ONE-PASS CONE INDEX
FIGURE 1
AVERAGE ONE-PASS INITIAL VANE SHEAR STRENGTH IN PSI
FIGURE 2
AVERAGE ONE-PASS DENSITY IN G/CM³
FIGURE 3
WET SNOW
MOIST SNOW
DRY SNOW

PLATE 22

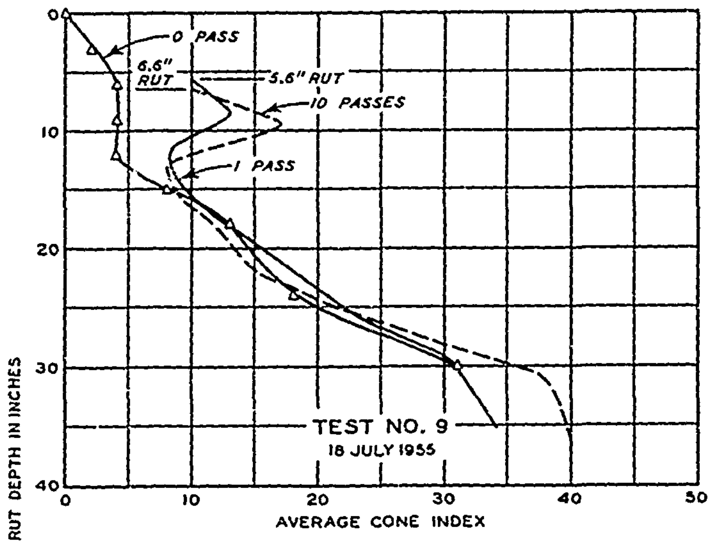


FIGURE 1. WEASEL

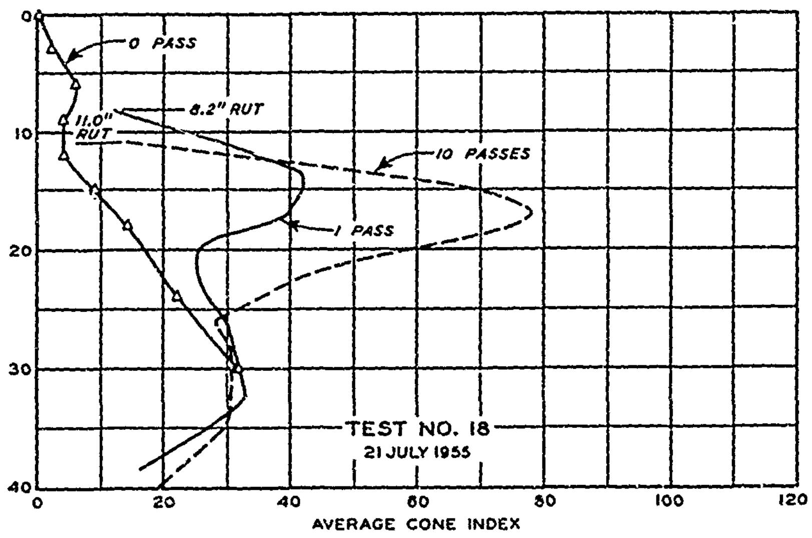


FIGURE 2. STD D6 TRACTOR (30-IN. TRACK)

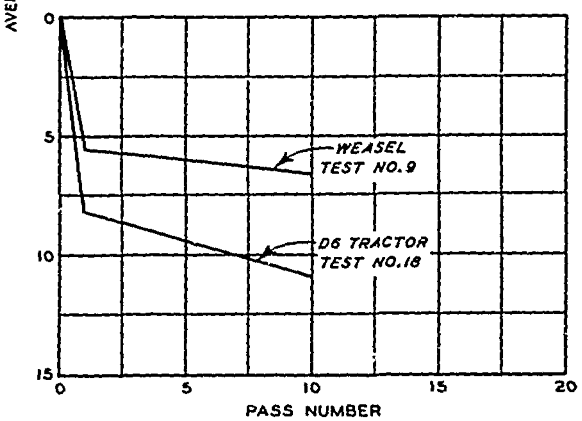


FIGURE 3

LEGEND

- □ WET SNOW (Wd)
- ○ MOIST SNOW (Wc)
- △ DRY SNOW (Wa)

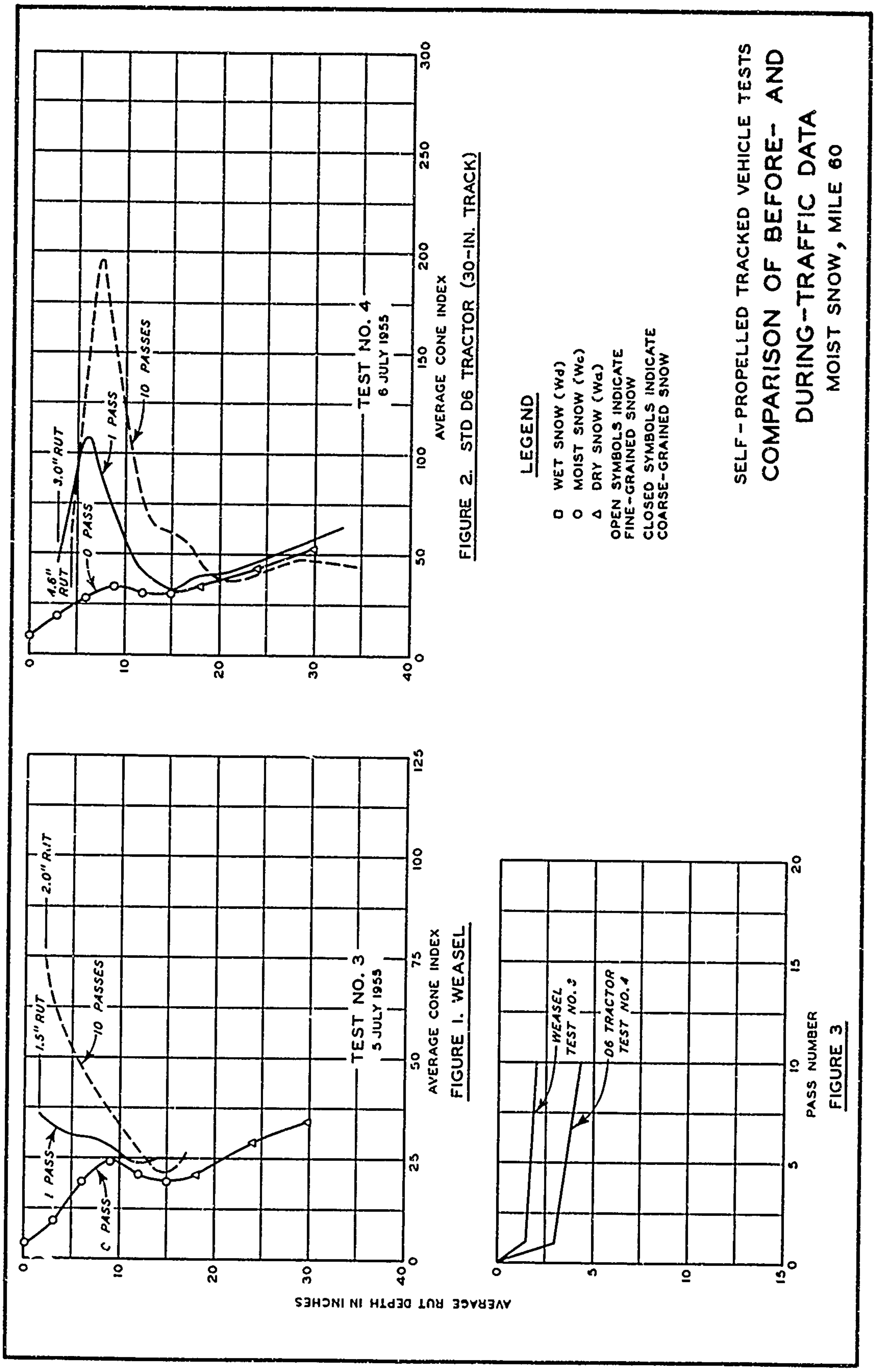
OPEN SYMBOLS INDICATE FINE-GRAINED SNOW

CLOSED SYMBOLS INDICATE COARSE-GRAINED SNOW

SELF-PROPELLED TRACKED VEHICLE TESTS

COMPARISON OF BEFORE- AND DURING-TRAFFIC DATA

DRY SNOW, MILE 220



SELF-PROPELLED TRACKED VEHICLE TESTS
COMPARISON OF BEFORE- AND DURING-TRAFFIC DATA
MOIST SNOW, MILE 60

PLATE 24

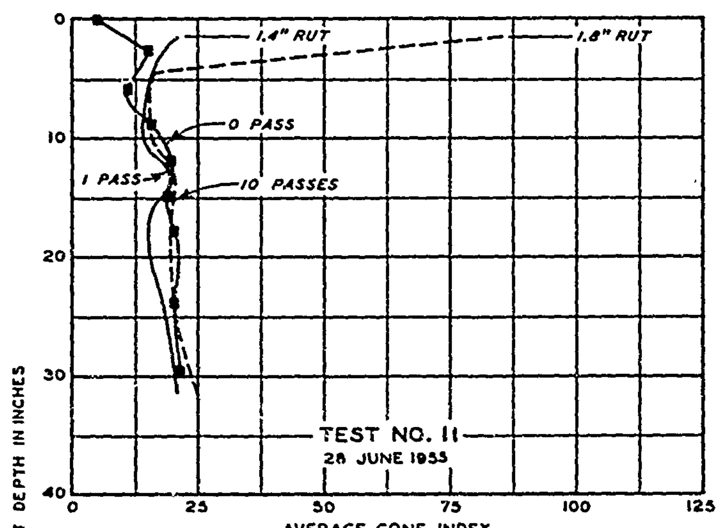


FIGURE 1. WEASEL

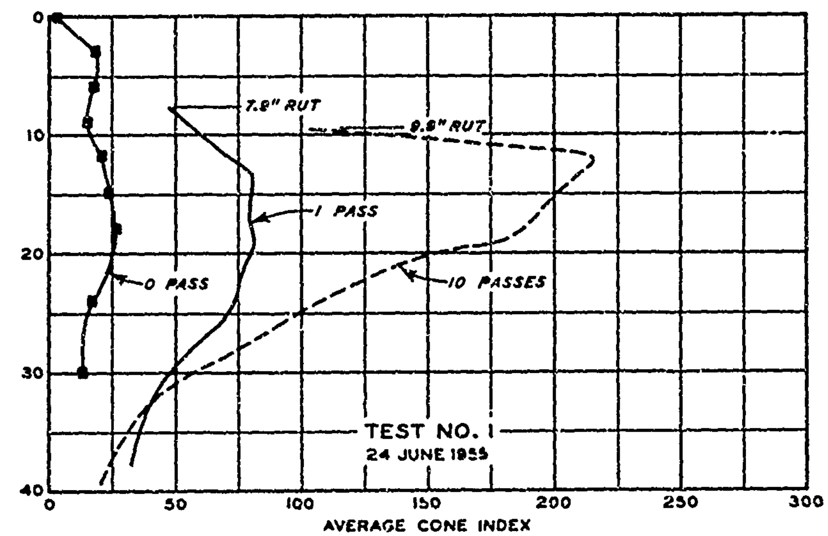


FIGURE 2. STD D6 TRACTOR (30-IN. TRACK)

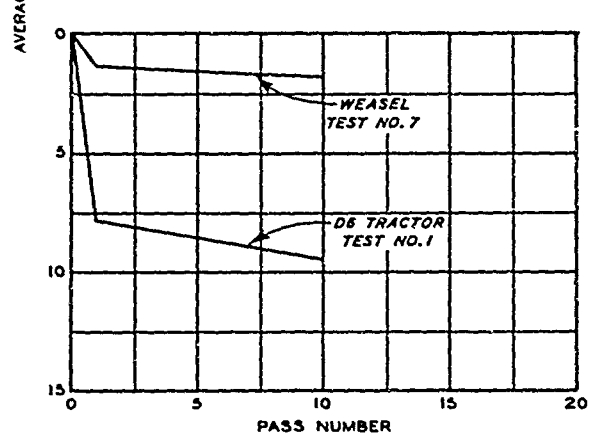


FIGURE 3

LEGEND

- □ WET SNOW (Wd)
- ○ MOIST SNOW (Wc)
- △ DRY SNOW (Wa)

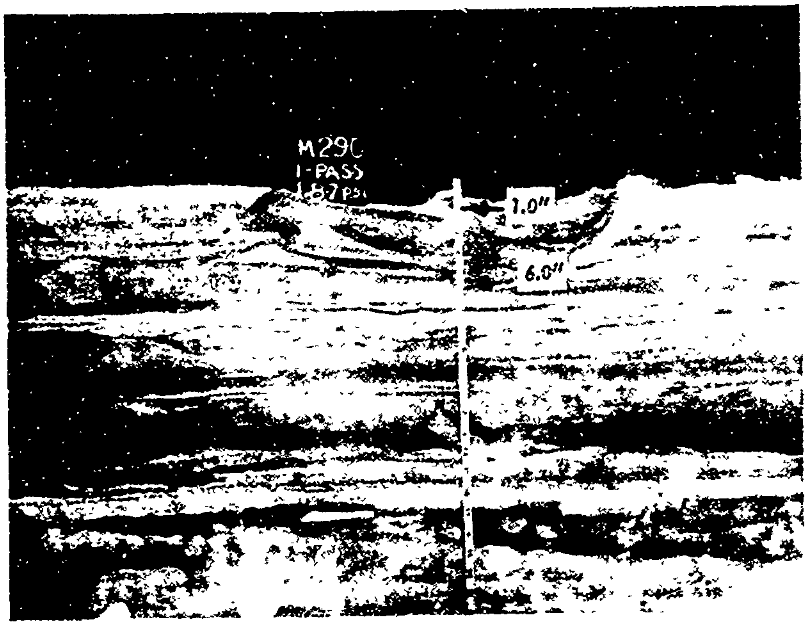
OPEN SYMBOLS INDICATE FINE-GRAINED SNOW

CLOSED SYMBOLS INDICATE COARSE-GRAINED SNOW

SELF-PROPELLED TRACKED VEHICLE TESTS

COMPARISON OF BEFORE- AND DURING-TRAFFIC DATA

WET SNOW, MILE 7



WEASEL M29C

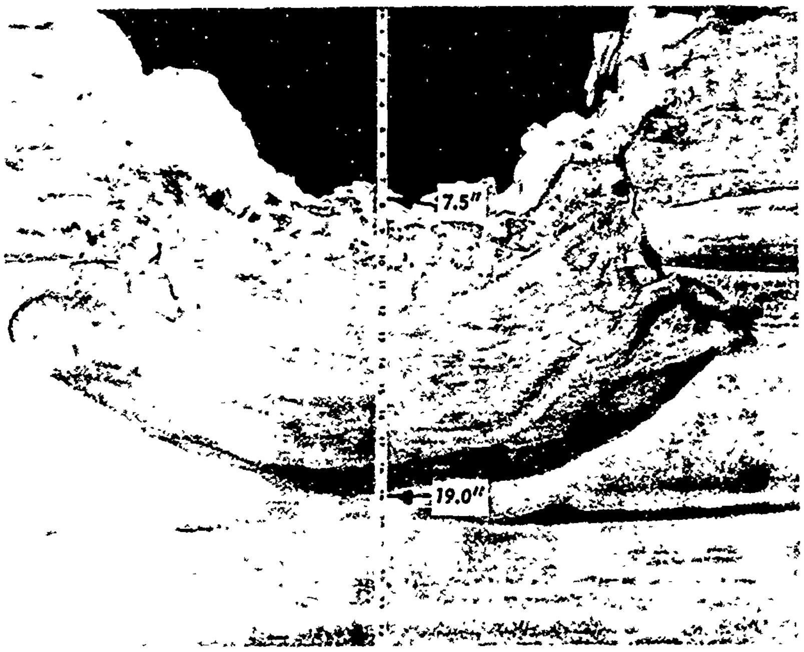
LGP-D8 TRACTOR

DRY SNOW

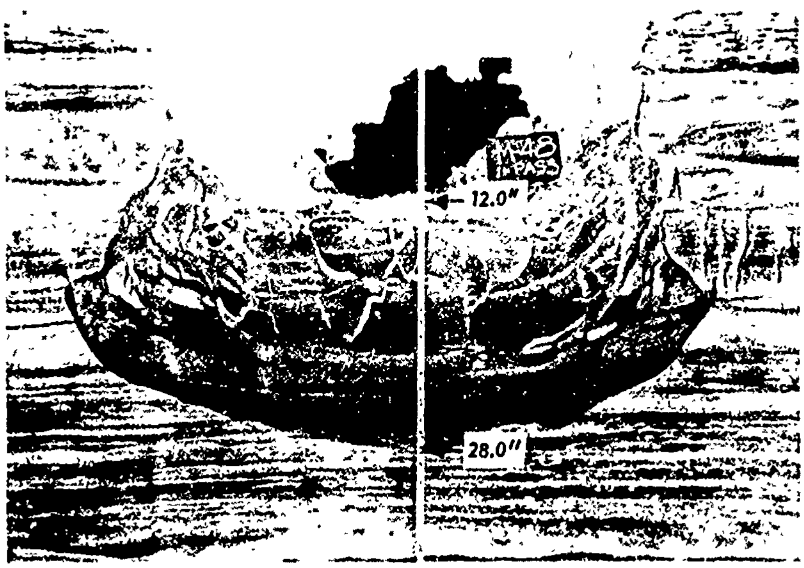
STRESS PATTERNS AFTER
ONE-PASS TRAFFIC

WEASEL M29C AND LGP-D8 TRACTOR

SHEET 1 OF 6



HI-SPEED TRACTOR M5A4



MEDIUM TANK M48

DRY SNOW

STRESS PATTERNS AFTER
ONE-PASS TRAFFIC

HI-SPEED TRACTOR M5A4 AND
MEDIUM TANK M48

SHEET 2 OF 6

WEASEL M29C

LGP-D8 TRACTOR

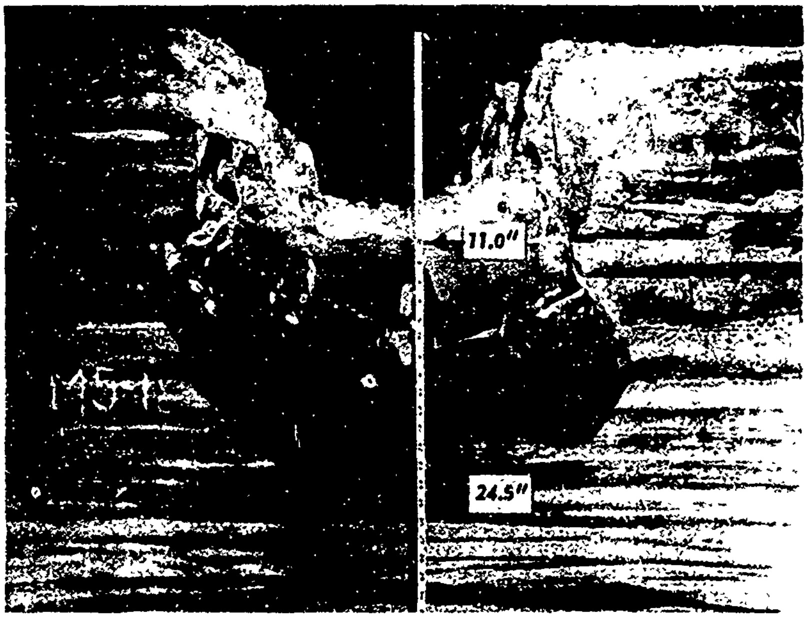
MOIST SNOW

STRESS PATTERNS AFTER
ONE-PASS TRAFFIC

WEASEL M29C AND LGP-D8 TRACTOR

SHEET 3 OF 6

PLATE 26



HI-SPEED TRACTOR M5A4

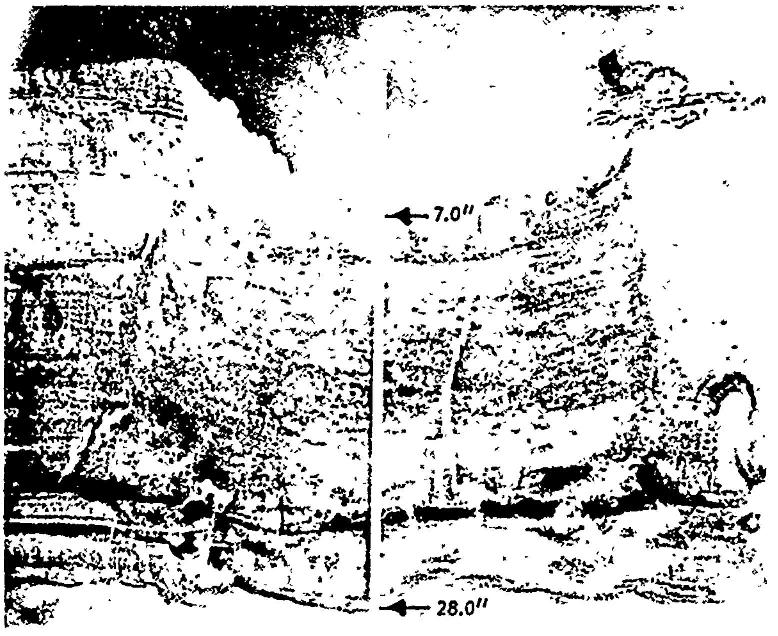
MEDIUM TANK M48

MOIST SNOW

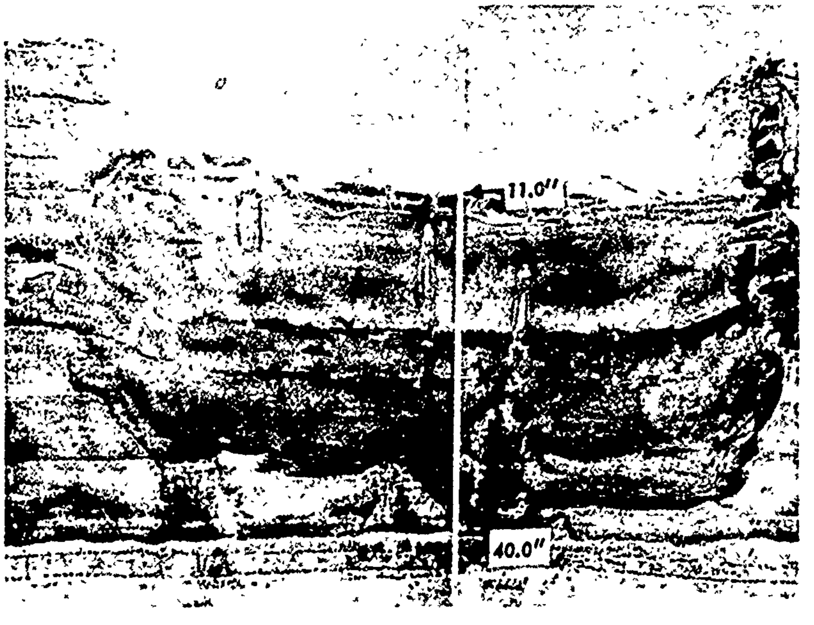
STRESS PATTERNS AFTER
ONE-PASS TRAFFIC

HI-SPEED TRACTOR M5A4 AND
MEDIUM TANK M48

SHEET 4 OF 6



WEASEL M29C



LGP-D8 TRACTOR

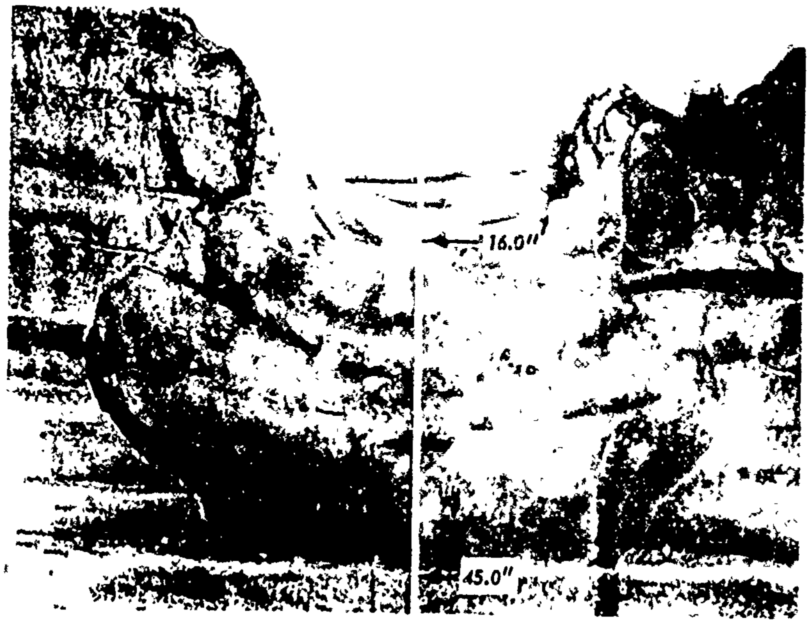
WET SNOW

STRESS PATTERNS AFTER
ONE-PASS TRAFFIC

WEASEL M29C AND LGP-D8 TRACTOR

SHEET 5 OF 6

HI-SPEED TRACTOR M5A4



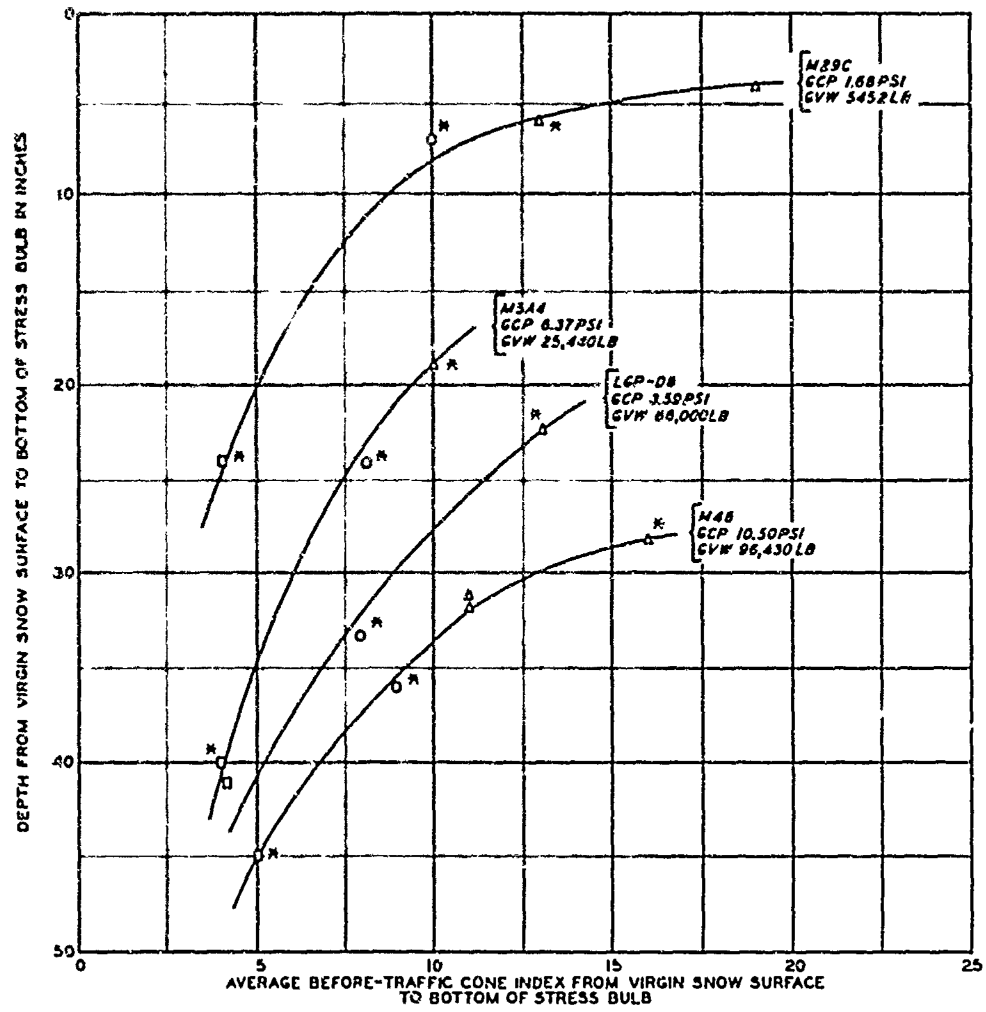
MEDIUM TANK M48

WET SNOW

STRESS PATTERNS AFTER ONE-PASS TRAFFIC

HI-SPEED TRACTOR M5A4 AND MEDIUM TANK M48

SHEET 6 OF 6



LEGEND

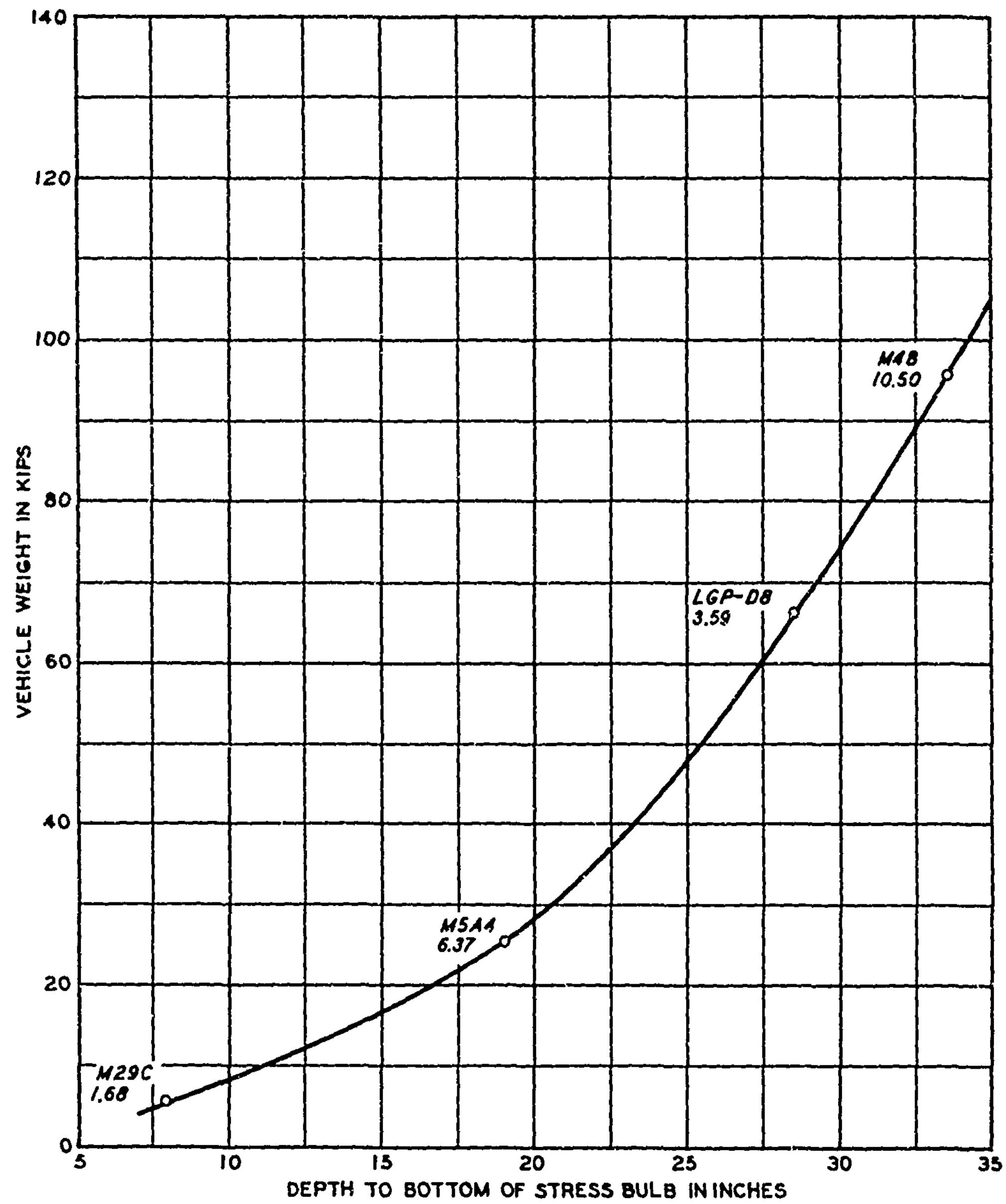
□ WET SNOW
○ MOIST SNOW
△ DRY SNOW

OPEN SYMBOLS INDICATE FINE-GRAINED SNOW
CLOSED SYMBOLS INDICATE COARSE-GRAINED SNOW
GCP GROUND-CONTACT PRESSURE
GVW GROSS VEHICLE WEIGHT

NOTE: * PHOTOGRAPHS FOR THESE STRESS PATTERNS SHOWN IN PLATE 26, SHEETS 1 - 6.

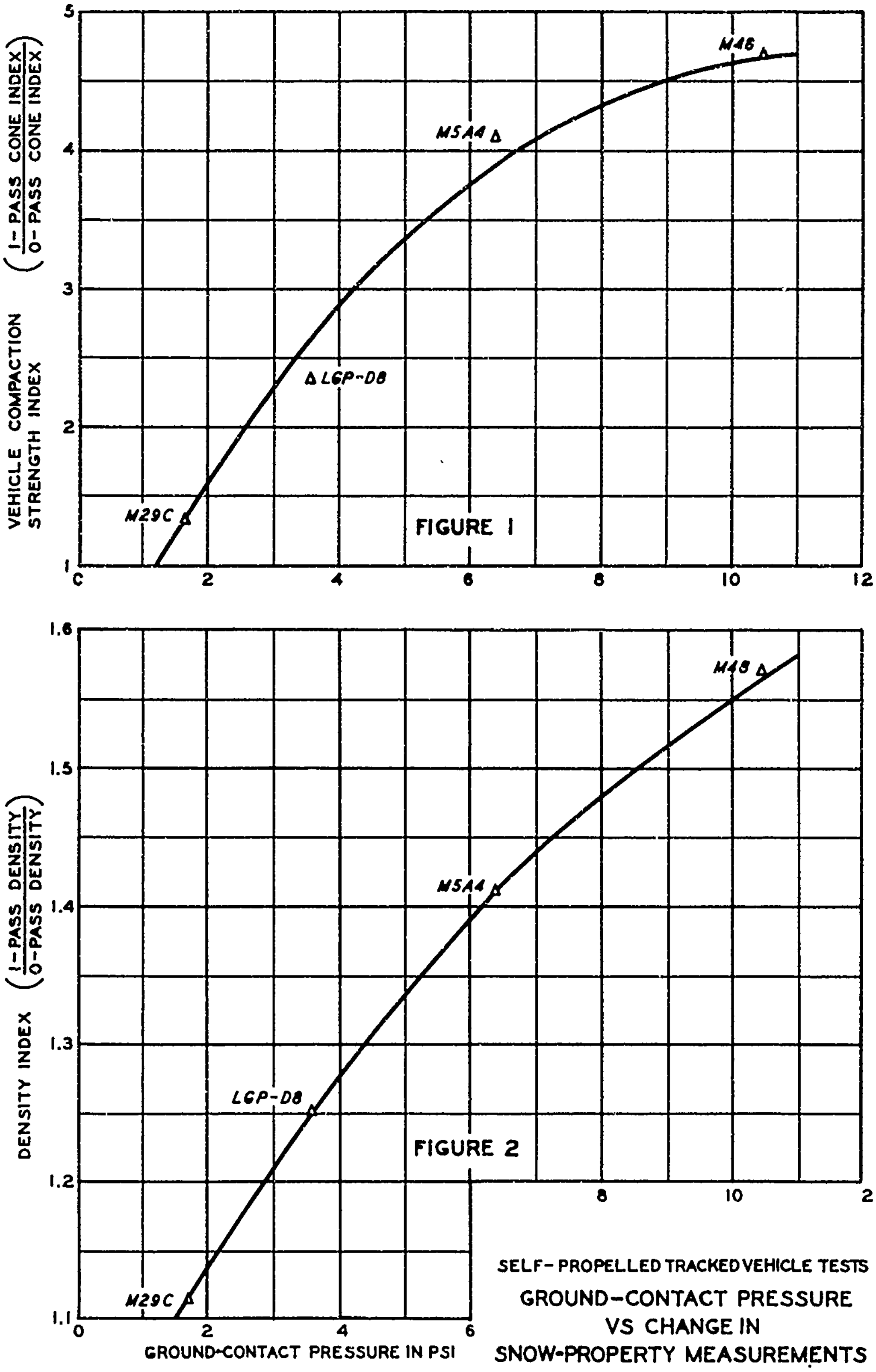
SELF-PROPELLED TRACKED VEHICLE TESTS

BEFORE-TRAFFIC CONE INDEX VS DEPTH TO BOTTOM OF STRESS BULB



SELF-PROPELLED TRACKED VEHICLE TESTS

DEPTH TO BOTTOM OF
STRESS BULB AT 10 CONE INDEX
VS VEHICLE WEIGHT



SELF-PROPELLED TRACKED VEHICLE TESTS

GROUND-CONTACT PRESSURE VS CHANGE IN SNOW-PROPERTY MEASUREMENTS AFTER ONE PASS

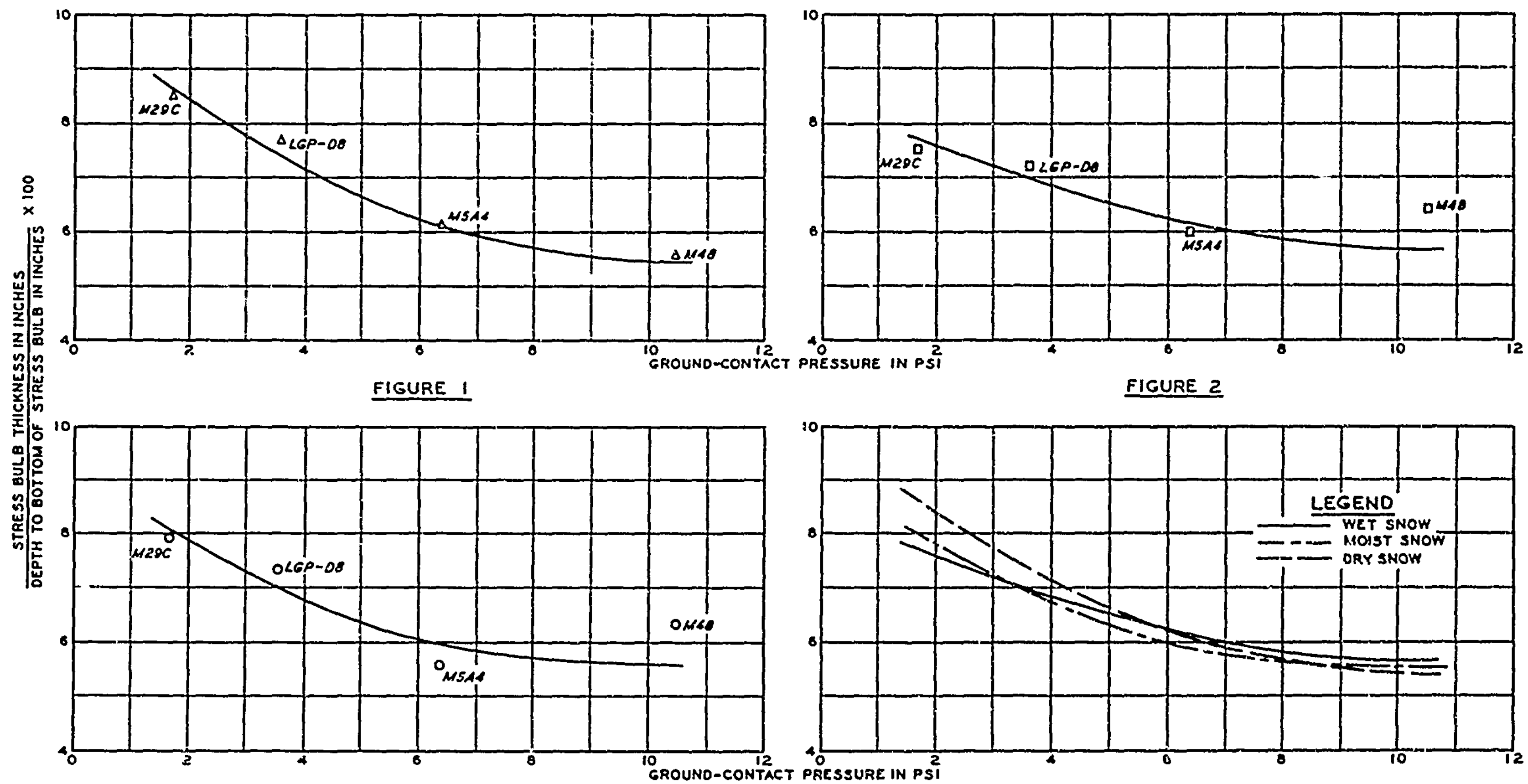


FIGURE 1 FIGURE 2

FIGURE 3 FIGURE 4

LEGEND

□ WET SNOW
○ MOIST SNOW
△ DRY SNOW

OPEN SYMBOLS INDICATE FINE-GRAINED SNOW.

SELF-PROPELLED TRACKED VEHICLE TESTS

GROUND-CONTACT PRESSURE VS STRESS BULB THICKNESS-DEPTH TO BOTTOM OF STRESS BULB RATIO

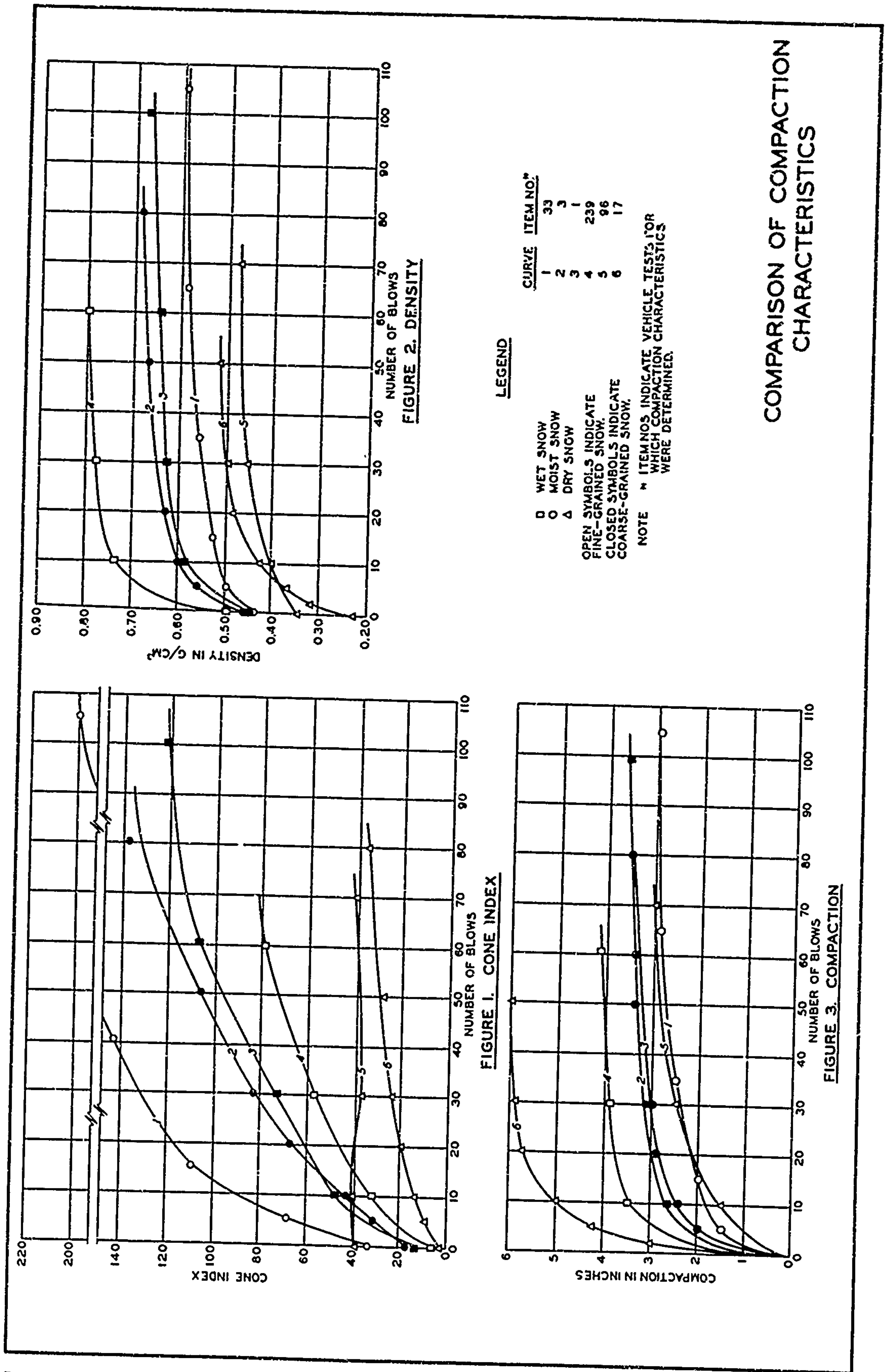


FIGURE 1. CONE INDEX

FIGURE 2. DENSITY

FIGURE 3. COMPACTION

PLATE 31

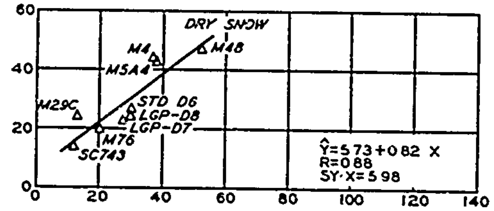


FIGURE 1

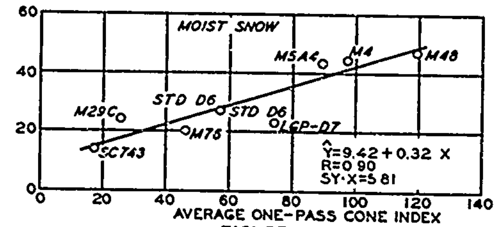


FIGURE 2

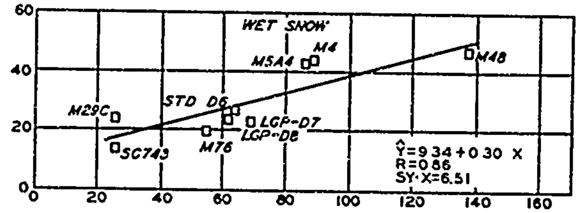


FIGURE 3

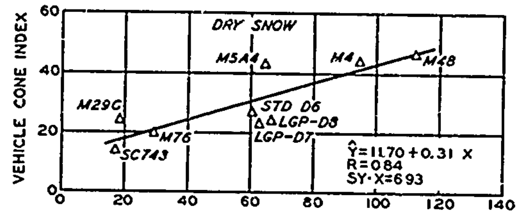


FIGURE 4

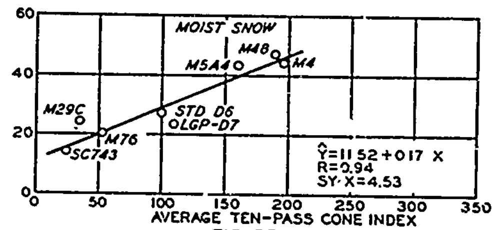


FIGURE 5

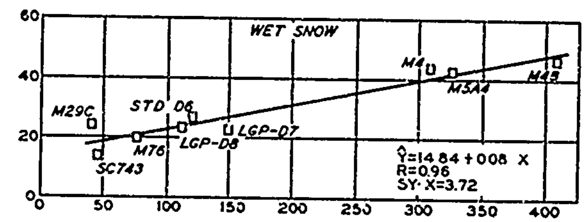


FIGURE 6

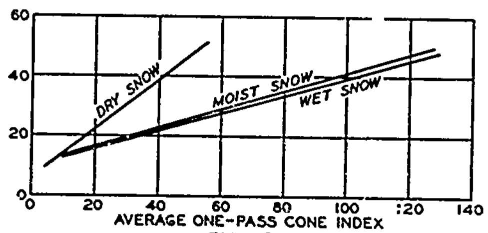


FIGURE 7

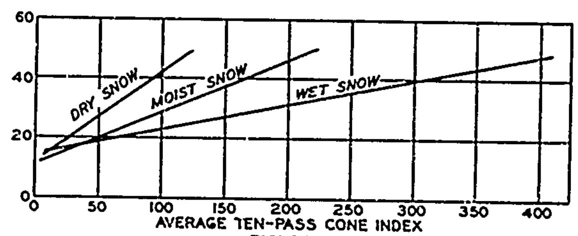


FIGURE 8

LEGEND

VEHICLE	GROUND-CONTACT PRESSURE, PSI	VEHICLE CONE INDEX
SNO-CAT 743	1.02	14
WEASEL M29C	1.68	24
OTTER M76	1.72	20
LGP-D7 TRACTOR	2.89	23
STD D6 TRACTOR	3.17	27
LGP-D8 TRACTOR	3.59	24
HI-SPEED TRACTOR M5A4	6.37	43
HI-SPEED TRACTOR M4	7.02	44
MEDIUM TANK M48	10.50	47

Δ DRY SNOW   O MOIST SNOW   □ WET SNOW

SUMMARY CURVES

SELF-PROPELLED TRACKED VEHICLE TESTS

AFTER-TRAFFIC CONE INDEX VS VEHICLE CONE INDEX

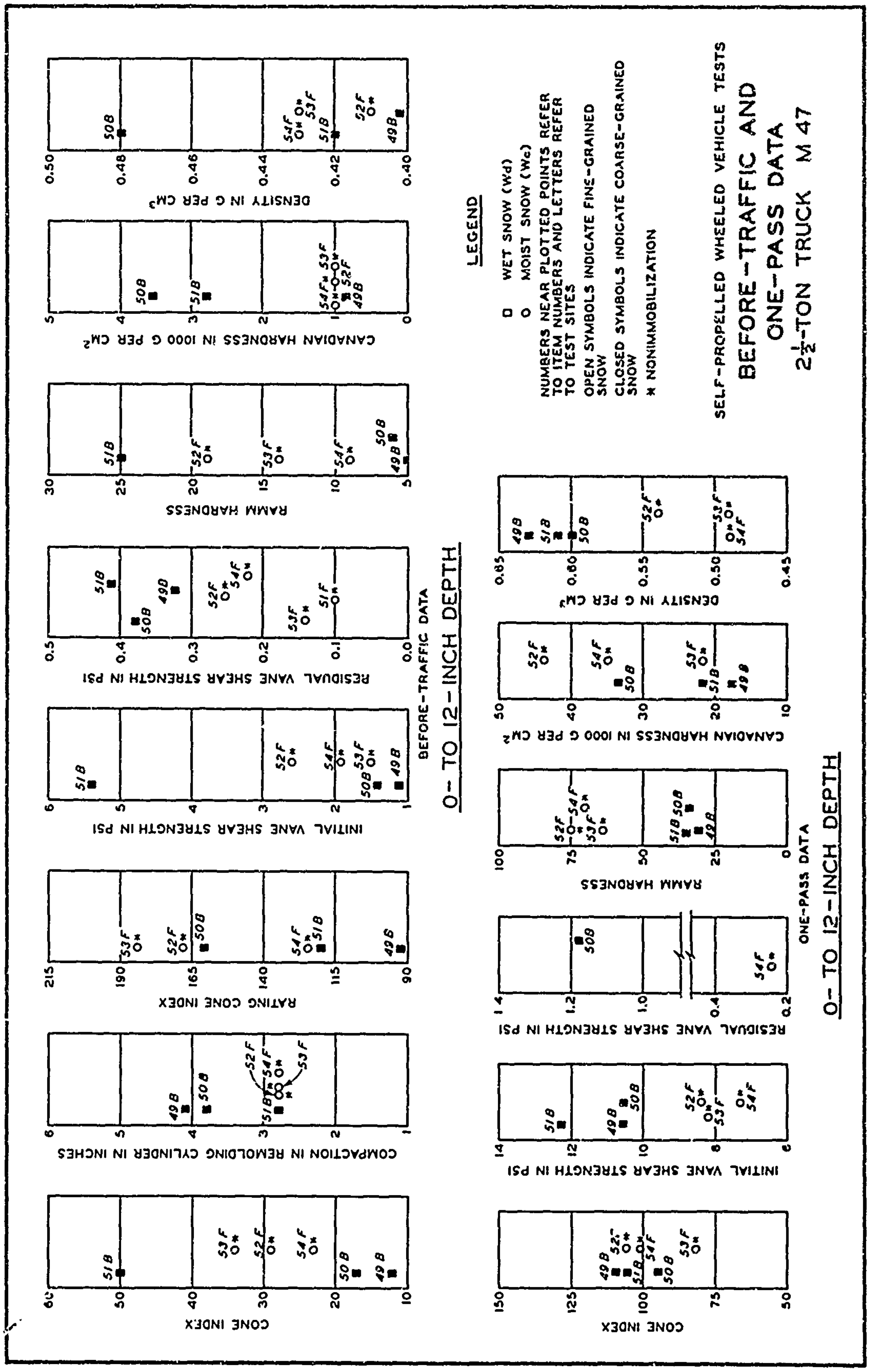

SELF-PROPELLED WHEELED VEHICLE TESTS
BEFORE-TRAFFIC AND
ONE-PASS DATA
2½-TON TRUCK M 47
LEGEND
□ WET SNOW (Wd)
○ MOIST SNOW (Wc)
NUMBERS NEAR PLOTTED POINTS REFER TO ITEM NUMBERS AND LETTERS REFER TO TEST SITES
OPEN SYMBOLS INDICATE FINE-GRAINED SNOW
CLOSED SYMBOLS INDICATE COARSE-GRAINED SNOW
* NONIMMOBILIZATION
BEFORE-TRAFFIC DATA
0- TO 12-INCH DEPTH
ONE-PASS DATA
0- TO 12-INCH DEPTH
DENSITY IN G PER CM³
CANADIAN HARDNESS IN 1000 G PER CM²
RAMM HARDNESS
RESIDUAL VANE SHEAR STRENGTH IN PSI
INITIAL VANE SHEAR STRENGTH IN PSI
RATING CONE INDEX
COMPACTION IN REMOLDING CYLINDER IN INCHES
CONE INDEX

PLATE 33

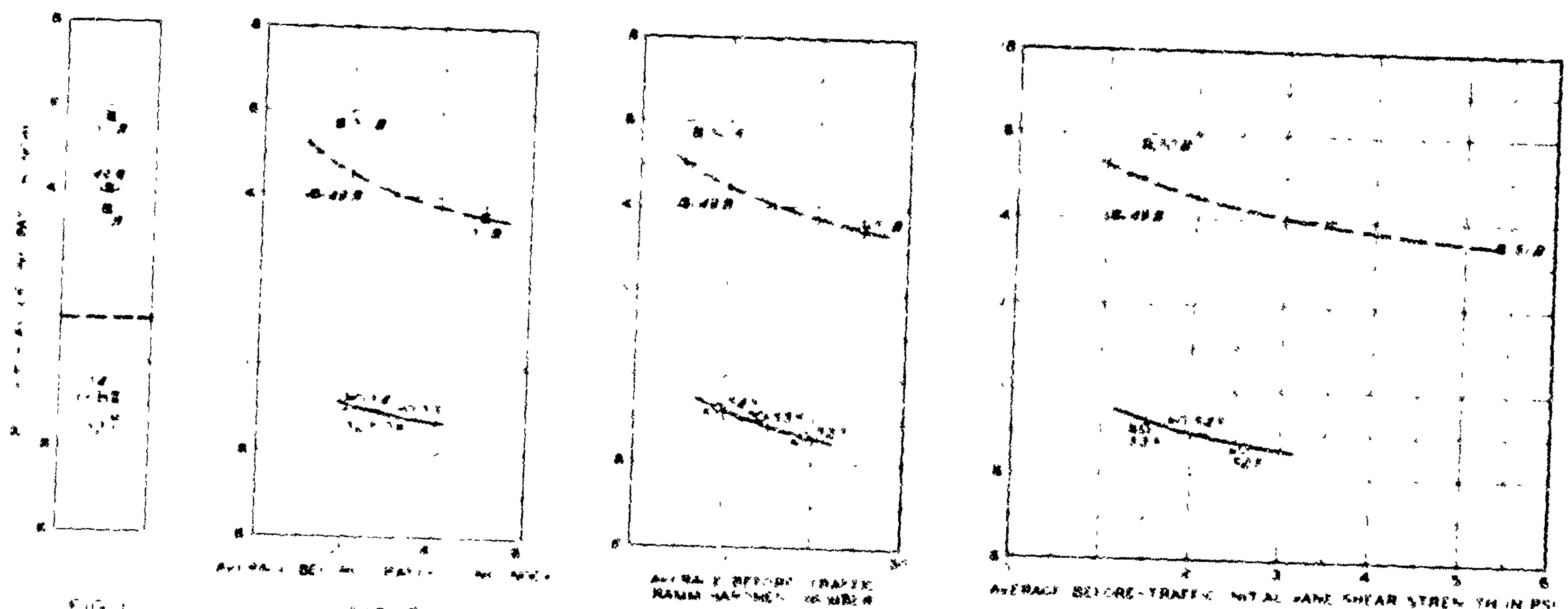


FIG. 1 FIG. 2 FIG. 3 FIG. 4

0- TO 12-INCH DEPTH

SELF-PROPELLED WHEELED VEHICLE TESTS

BEFORE-TRAFFIC STRENGTH MEASUREMENTS VS RUT DEPTH AFTER ONE PASS 2½-TON TRUCK M47

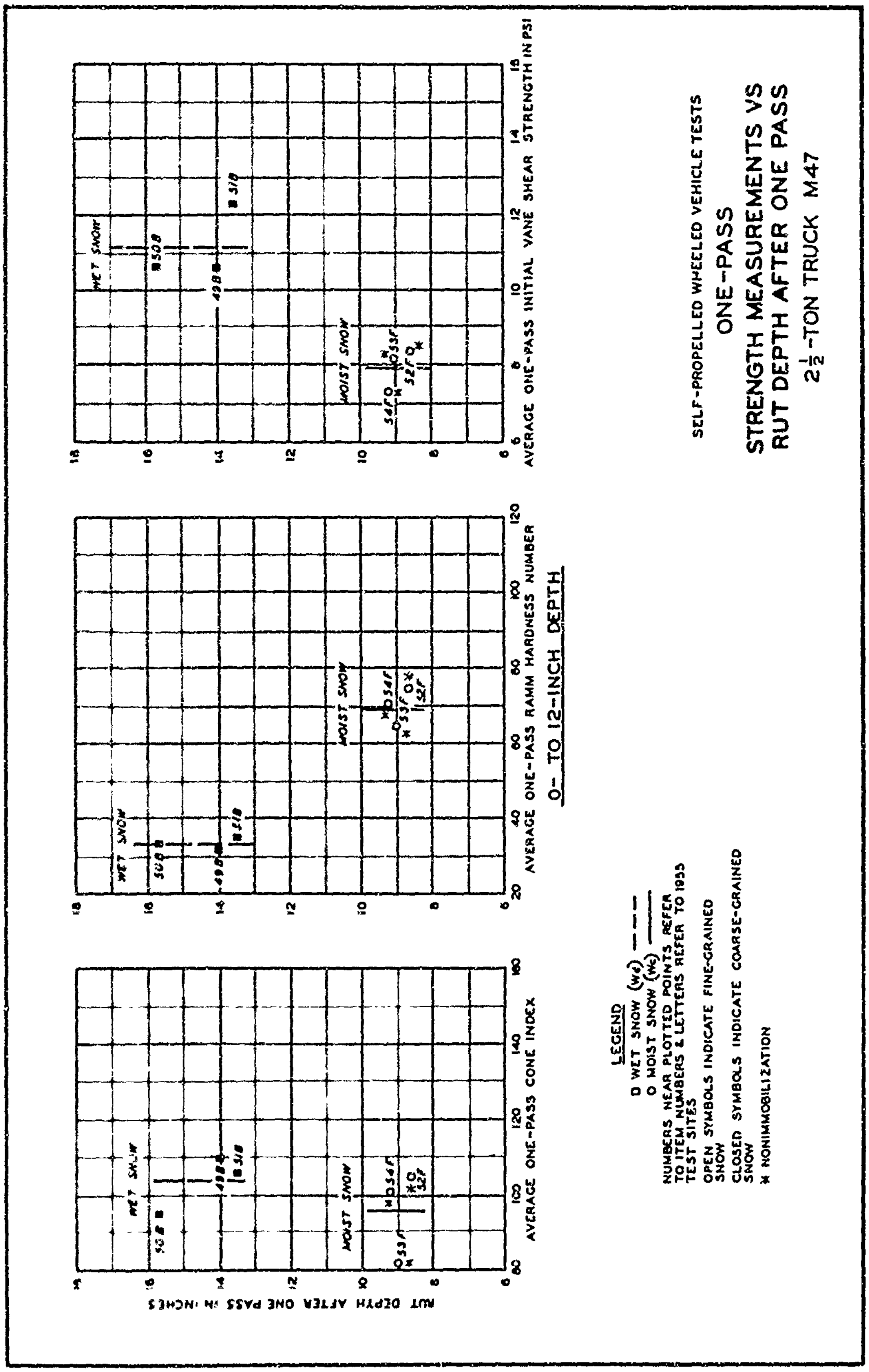
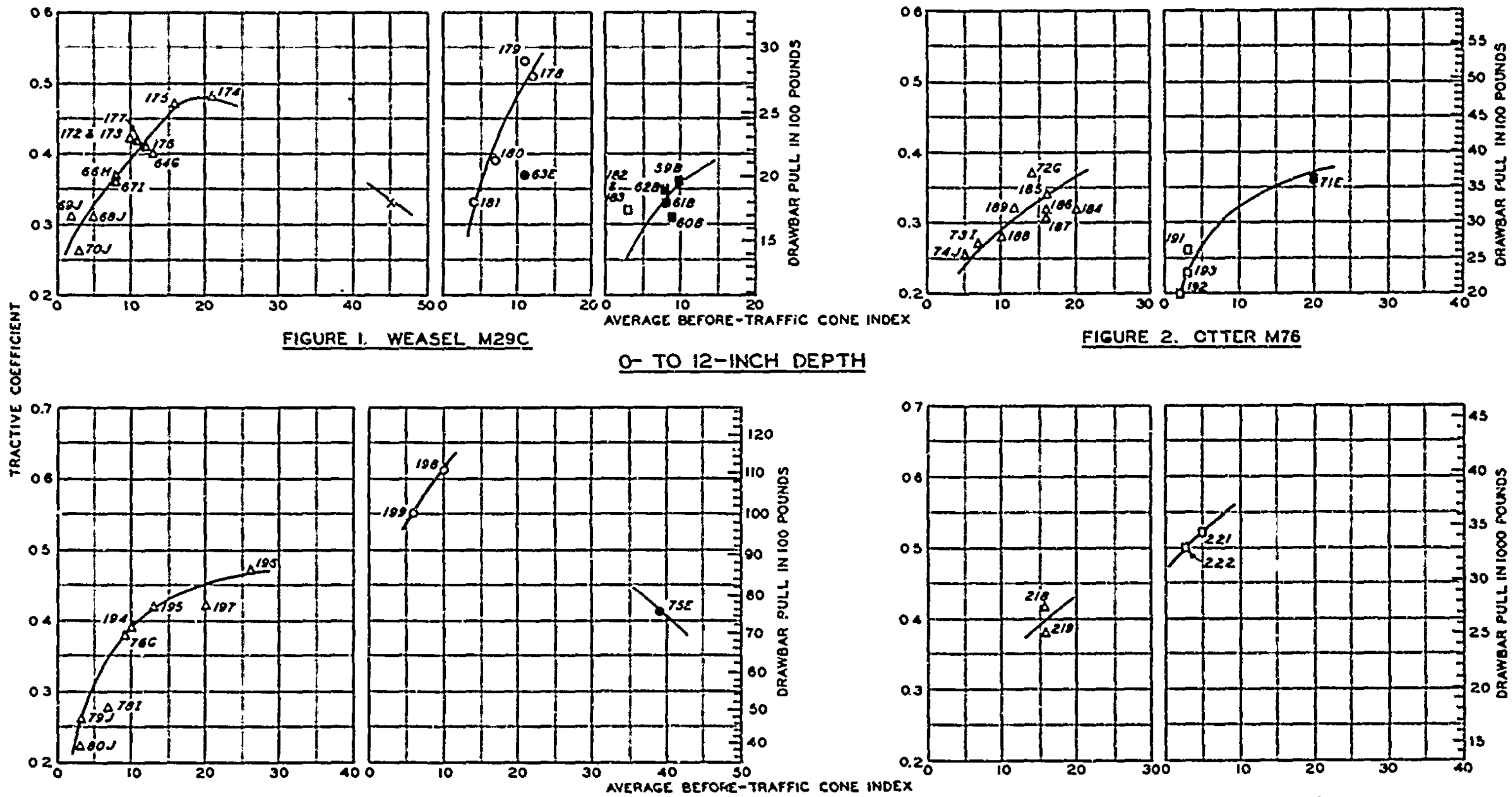

SELF-PROPELLED WHEELED VEHICLE TESTS
ONE-PASS
STRENGTH MEASUREMENTS VS
RUT DEPTH AFTER ONE PASS
2½-TON TRUCK M47
0- TO 12-INCH DEPTH
RUT DEPTH AFTER ONE PASS IN INCHES
AVERAGE ONE-PASS CONE INDEX
AVERAGE ONE-PASS RAMM HARDNESS NUMBER
AVERAGE ONE-PASS INITIAL VANE SHEAR STRENGTH IN PSI
WET SNOW
MOIST SNOW
LEGEND
□ WET SNOW (Wc)
○ MOIST SNOW (Wc)
NUMBERS NEAR PLOTTED POINTS REFER TO ITEM NUMBERS & LETTERS REFER TO 1955 TEST SITES
OPEN SYMBOLS INDICATE FINE-GRAINED SNOW
CLOSED SYMBOLS INDICATE COARSE-GRAINED SNOW
* NONIMMOBILIZATION

PLATE 35



LEGEND

GREENLAND-1955 & 1957	GREENLAND-1954
□ WET SNOW (Wd)	x DRY SNOW (Db)
O MOIST SNOW (Wc)	
Δ DRY SNOW (Wa)	

NUMBERS NEAR PLOTTED POINTS REFER TO ITEM NUMBERS AND LETTERS REFER TO 1955 TEST SITES
OPEN SYMBOLS INDICATE FINE-GRAINED SNOW
CLOSED SYMBOLS INDICATE COARSE-GRAINED SNOW

TRACKED VEHICLE TOWING TESTS

BEFORE-TRAFFIC CONE INDEX VS MAXIMUM DRAWBAR PULL

SHEET 1 OF 2

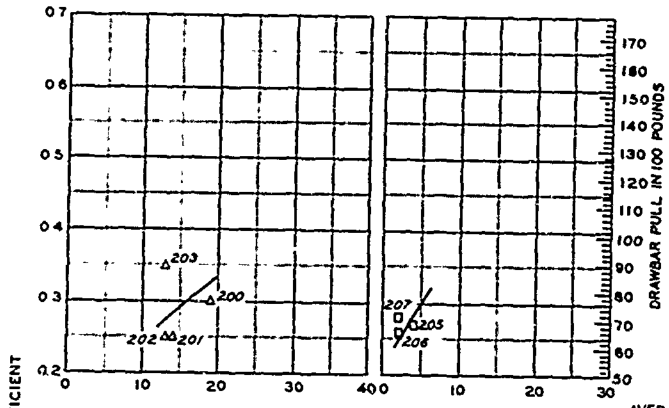


FIGURE 5. HI-SPEED TRACTOR M5A4

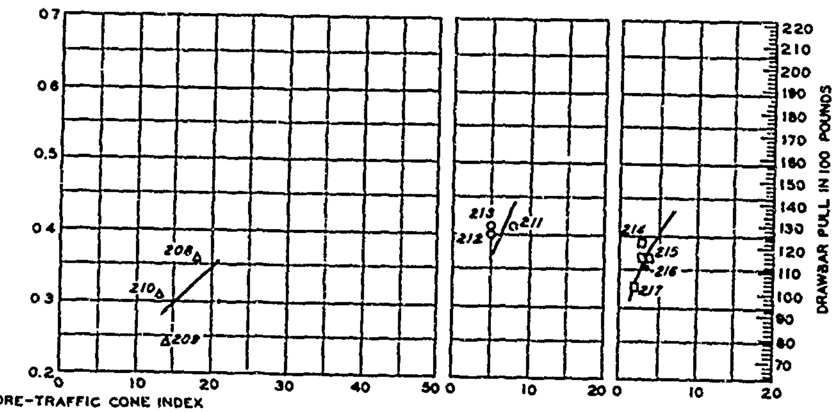


FIGURE 6 HI-SPEED TRACTOR M4

0- TO 12-INCH DEPTH

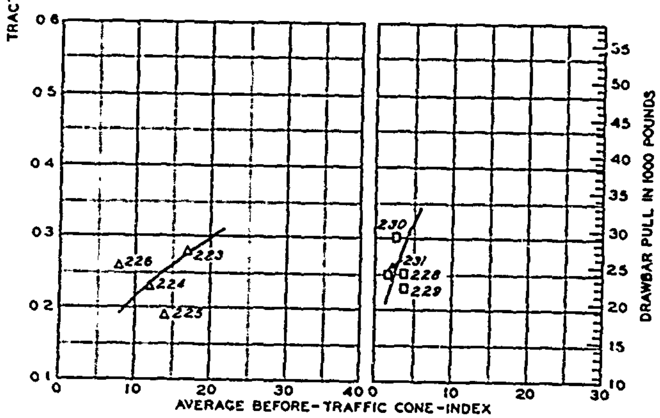


FIGURE 7. MEDIUM TANK M48
0- TO 12-INCH DEPTH

LEGEND

□ WET SNOW (Wd)
○ MOIST SNOW (Wc)
△ DRY SNOW (Wd)

NUMBERS NEAR PLOTTED POINTS REFER TO ITEM NUMBERS

OPEN SYMBOLS INDICATE FINE-GRAINED SNOW

CLOSED SYMBOLS INDICATE COARSE-GRAINED SNOW

TRACKED VEHICLE TOWING TESTS

BEFORE-TRAFFIC CONE INDEX VS MAXIMUM DRAWBAR PULL

SHEET 2 OF 2

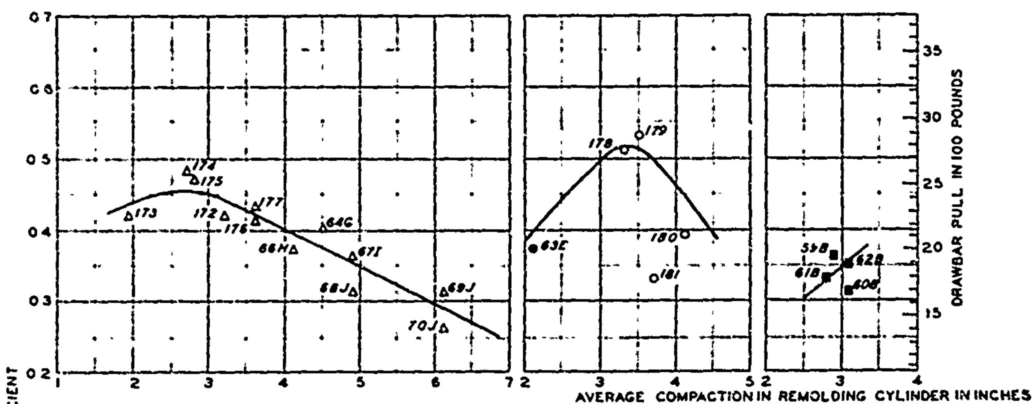


FIGURE 1. WEASEL M29C

0- TO 12-INCH DEPTH

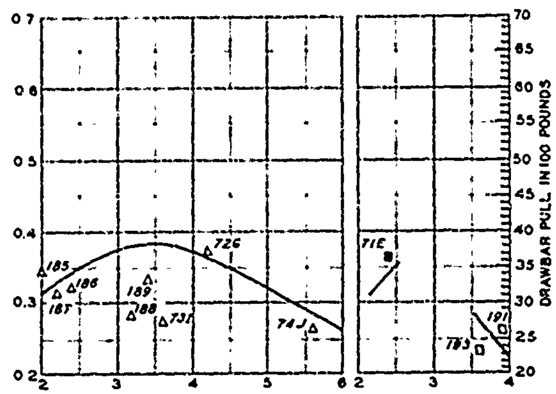


FIGURE 2. OTTER M76

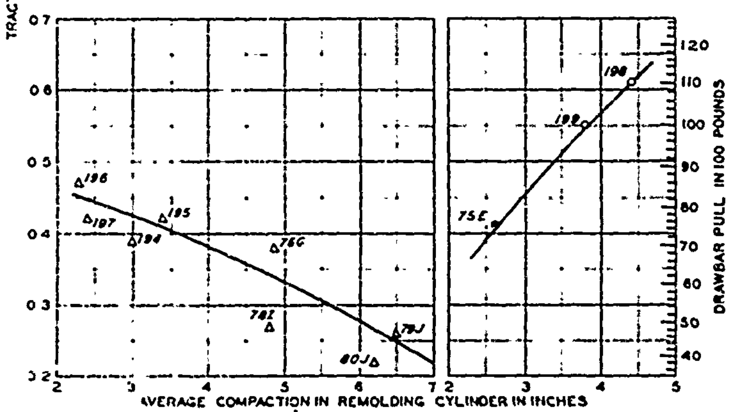


FIGURE 3 STD D6 TRACTOR (30-IN TRACK)

0- TO 12-INCH DEPTH

LEGEND

□ WET SNOW (Wd)
○ MOIST SNOW (Wc)
△ DRY SNOW (Wd)
NUMBERS NEAR PLOTTED POINTS REFER TO ITEM NUMBERS AND LETTERS REFER TO 1955 TEST SITES
OPEN SYMBOLS INDICATE FINE-GRAINED SNOW
CLOSED SYMBOLS INDICATE COARSE-GRAINED SNOW

TRACKED VEHICLE TOWING TESTS

BEFORE-TRAFFIC COMPACTION IN REMOLDING CYLINDER VS MAXIMUM DRAWBAR PULL

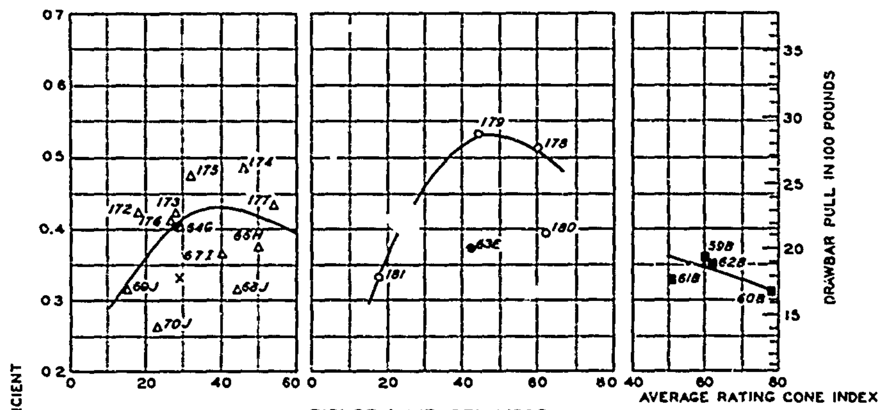


FIGURE 1 WEASEL M29C

0- TO 12-INCH DEPTH

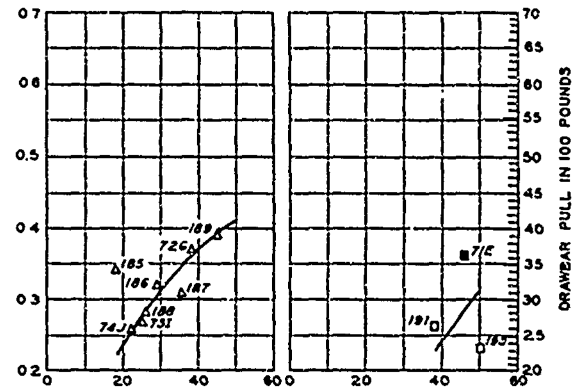


FIGURE 2. OTTER M76

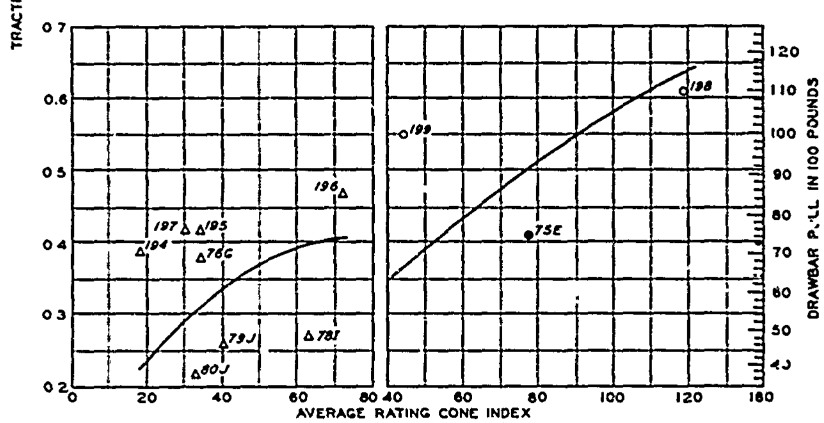


FIGURE 3. STD D6 TRACTOR (30-IN. TRACK)

0- TO 12-INCH DEPTH

LEGEND

GREENLAND-1955 & 1957	GREENLAND-1954
□ WET SNOW (Wd)	X DRY SNOW (Db)
O MOIST SNOW (Wc)	
Δ DRY SNOW (Wa)	

NUMBERS NEAR PLOTTED POINTS REFER TO ITEM NUMBERS AND LETTERS REFER TC 1955 TEST SITES

OPEN SYMBOLS INDICATE FINE-GRAINED SNOW

CLOSED SYMBOLS INDICATE COARSE-GRAINED SNOW

TRACKED VEHICLE TOWING TESTS

BEFORE-TRAFFIC RATING CONE INDEX VS MAXIMUM DRAWBAR PULL

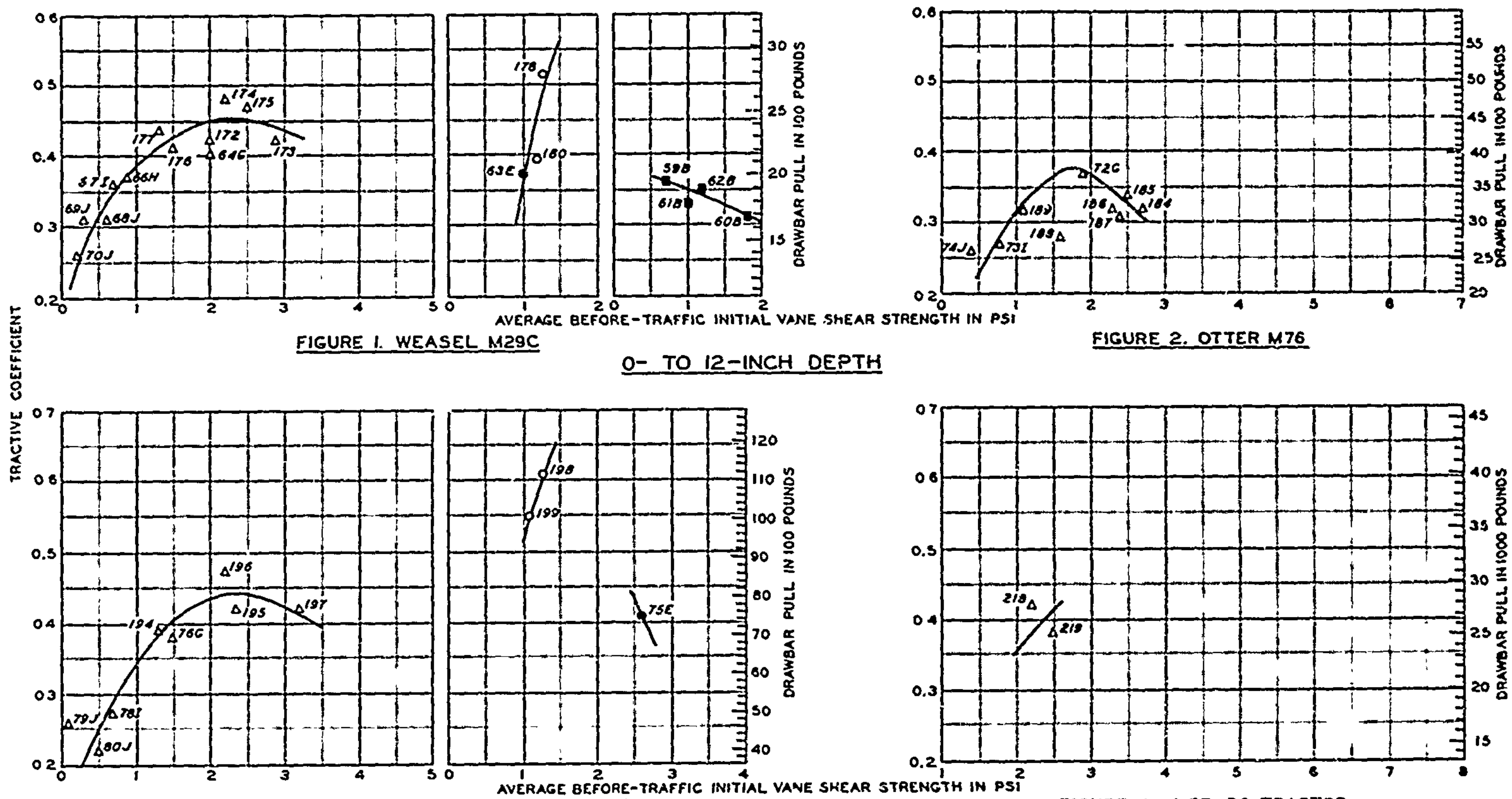


FIGURE 1. WEASEL M29C

FIGURE 2. OTTER M76

0- TO 12-INCH DEPTH

FIGURE 3 STD D6 TRACTOR (30-IN TRACK)

FIGURE 4 LGP-D8 TRACTOR

0- TO 12-INCH DEPTH

LEGEND

□ WET SNOW (Wd)
○ MOIST SNOW (Wc)
△ DRY SNOW (Wo)

NUMBERS NEAR PLOTTED POINTS REFER TO ITEM NUMBERS AND LETTERS REFER TO 1955 TEST SITES

OPEN SYMBOLS INDICATE FINE-GRAINED SNOW

CLOSED SYMBOLS INDICATE COARSE-GRAINED SNOW

TRACKED VEHICLE TOWING TESTS

BEFORE-TRAFFIC
INITIAL VANE SHEAR STRENGTH VS
MAXIMUM DRAWBAR PULL

SHEET 1 OF 2

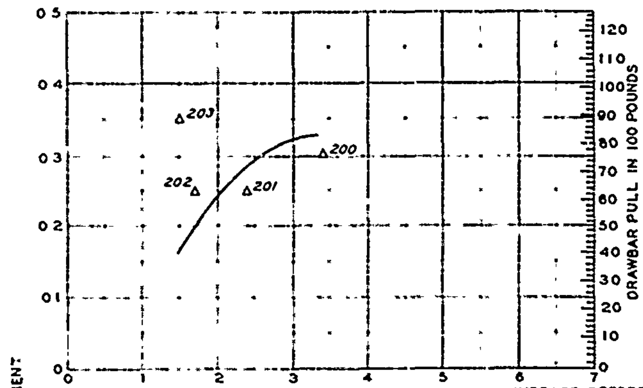
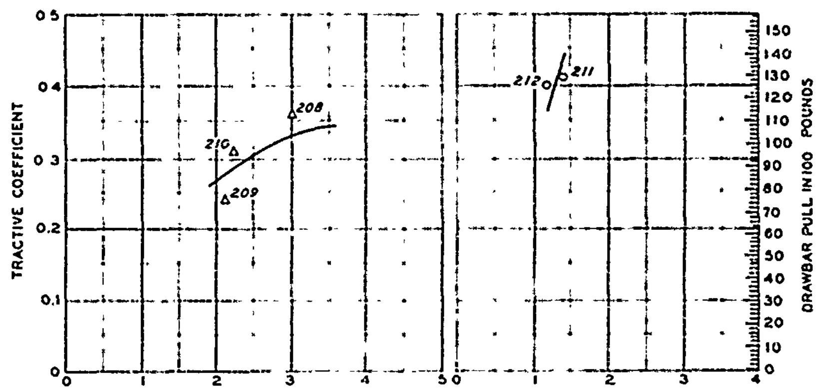


FIGURE 5 HI-SPEED TRACTOR M5A4



AVERAGE BEFORE-TRAFFIC INITIAL VANE SHEAR STRENGTH IN PSI

FIGURE 6 HI-SPEED TRACTOR M4

0- TO 12-INCH DEPTH

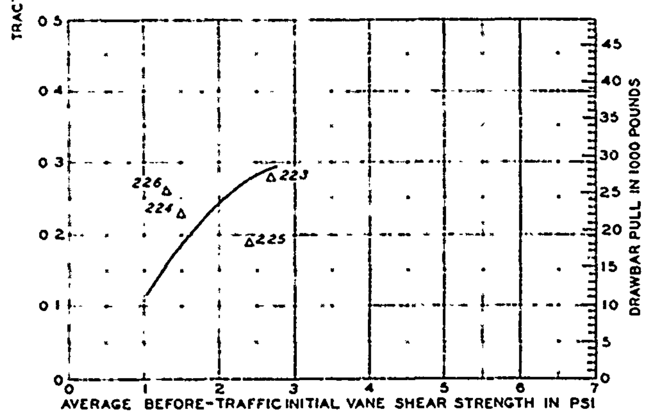


FIGURE 7. MEDIUM TANK M48

0- TO 12-INCH DEPTH

LEGEND

□ WET SNOW (Wd)
○ MOIST SNOW (Wc)
△ DRY SNOW (Wa)
NUMBERS NEAR PLOTTED POINTS REFER TO ITEM NUMBERS
OPEN SYMBOLS INDICATE FINE-GRAINED SNOW
CLOSED SYMBOLS INDICATE COARSE-GRAINED SNOW

TRACKED VEHICLE TOWING TESTS

BEFORE-TRAFFIC
INITIAL VANE SHEAR STRENGTH VS
MAXIMUM DRAWBAR PULL

SHEET 2 OF 2

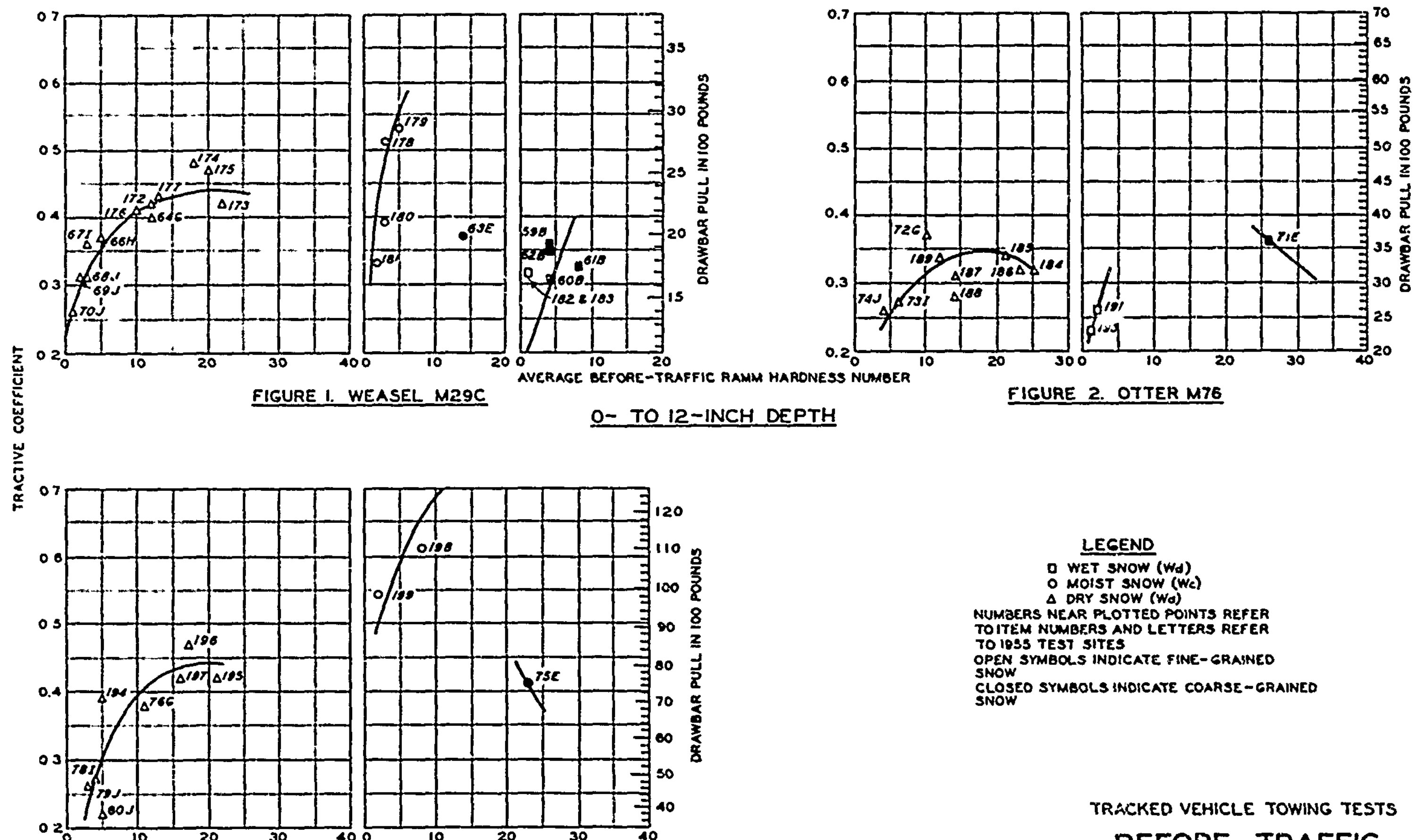


FIGURE 1. WEASEL M29C

0- TO 12-INCH DEPTH

FIGURE 2. OTTER M76

FIGURE 3 STD D6 TRACTOR (30-IN. TRACK)

0- TO 12-INCH DEPTH

TRACKED VEHICLE TOWING TESTS

BEFORE-TRAFFIC RAMM HARDNESS NUMBER VS MAXIMUM DRAWBAR PULL

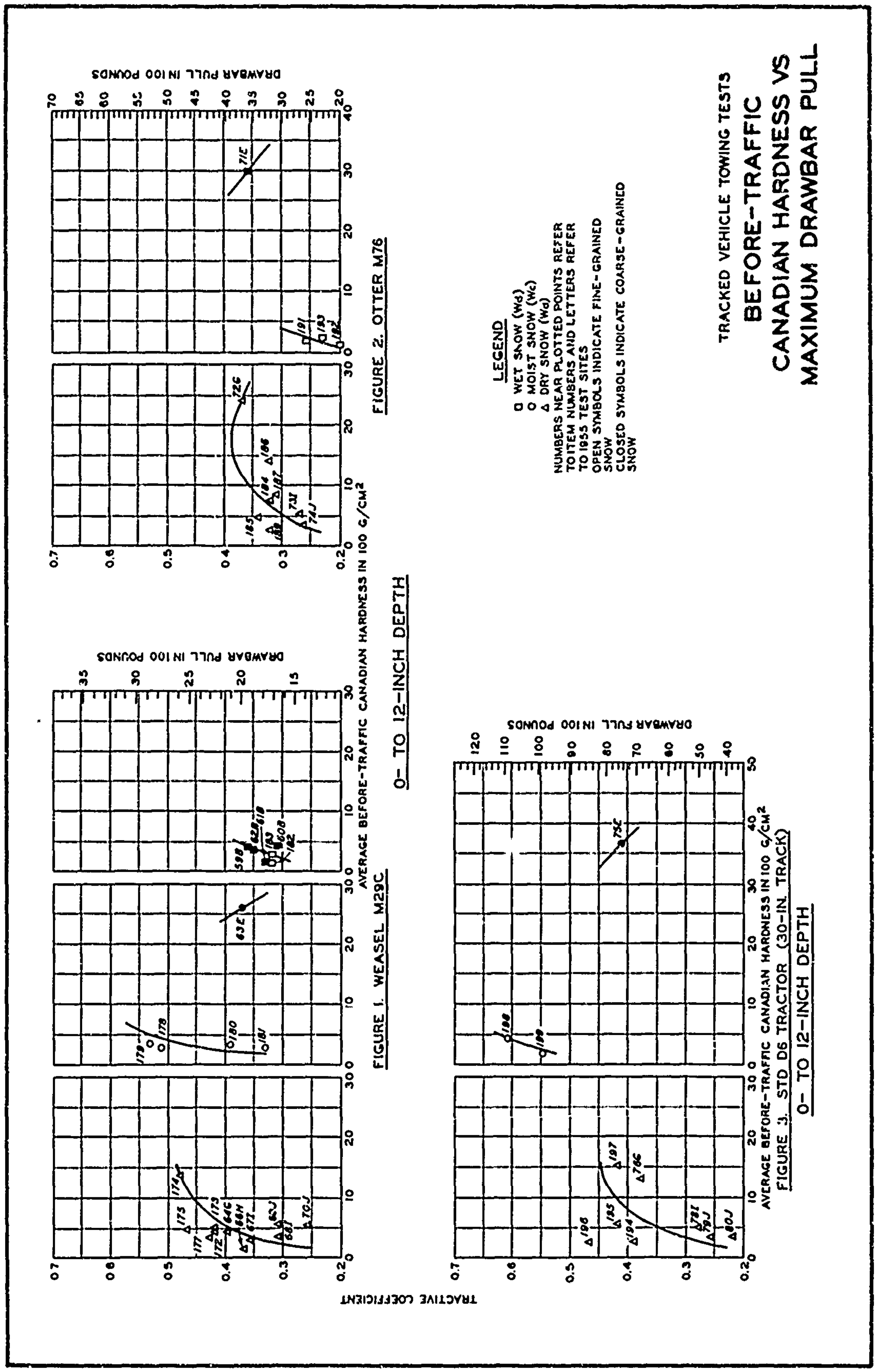
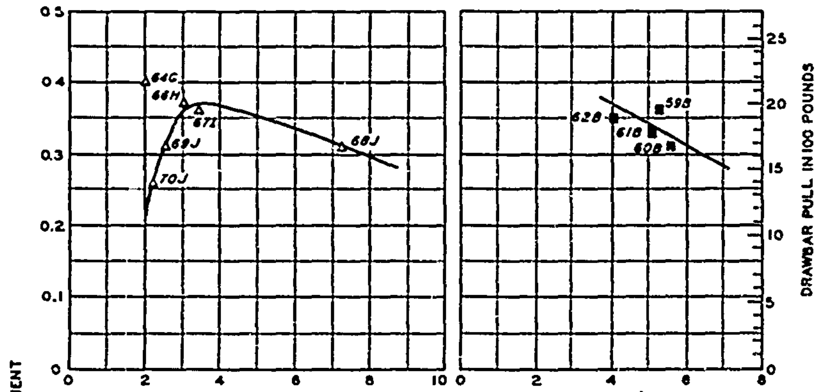
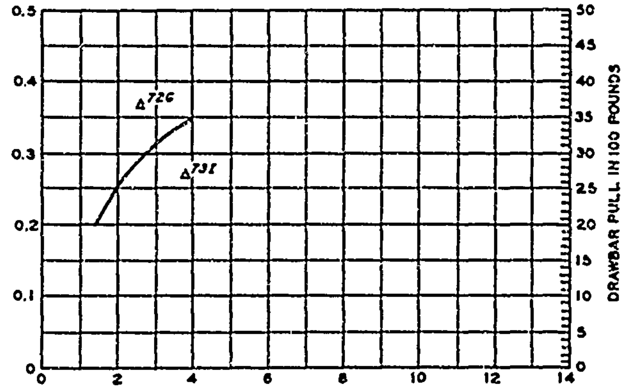

TRACKED VEHICLE TOWING TESTS
BEFORE-TRAFFIC
CANADIAN HARDNESS VS
MAXIMUM DRAWBAR PULL
LEGEND
□ WET SNOW (Wd)
○ MOIST SNOW (Wc)
△ DRY SNOW (Wa)
NUMBERS NEAR PLOTTED POINTS REFER TO ITEM NUMBERS AND LETTERS REFER TO 1955 TEST SITES
OPEN SYMBOLS INDICATE FINE-GRAINED SNOW
CLOSED SYMBOLS INDICATE COARSE-GRAINED SNOW
FIGURE 1. WEASEL M29C
FIGURE 2. OTTER M76
0- TO 12-INCH DEPTH
FIGURE 3. STD D6 TRACTOR (30-IN. TRACK)
0- TO 12-INCH DEPTH
AVERAGE BEFORE-TRAFFIC CANADIAN HARDNESS IN 100 G/CM²
TRACTIVE COEFFICIENT
DRAWBAR PULL IN 100 POUNDS

PLATE 41



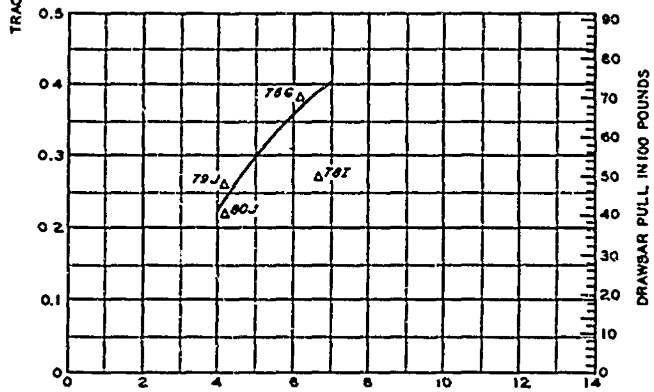


BEFORE-TRAFFIC $2\frac{1}{4}$-INCH TORQUE TUBE INITIAL SHEAR STRENGTH IN PSI

FIGURE 1. WEASEL M29C

FIGURE 2. OTTER M76

0- TO 12-INCH DEPTH



BEFORE-TRAFFIC $2\frac{1}{4}$-INCH TORQUE TUBE INITIAL SHEAR STRENGTH IN PSI

FIGURE 3. STD D6 TRACTOR (30-IN. TRACK)

0- TO 12-INCH DEPTH

LEGEND

□ WET SNOW (Wd)
○ MOIST SNOW (Wc)
△ DRY SNOW (Wa)

NUMBERS NEAR PLOTTED POINTS REFER TO ITEM NUMBERS AND LETTERS REFER TO 1955 TEST SITES

OPEN SYMBOLS INDICATE FINE-GRAINED SNOW

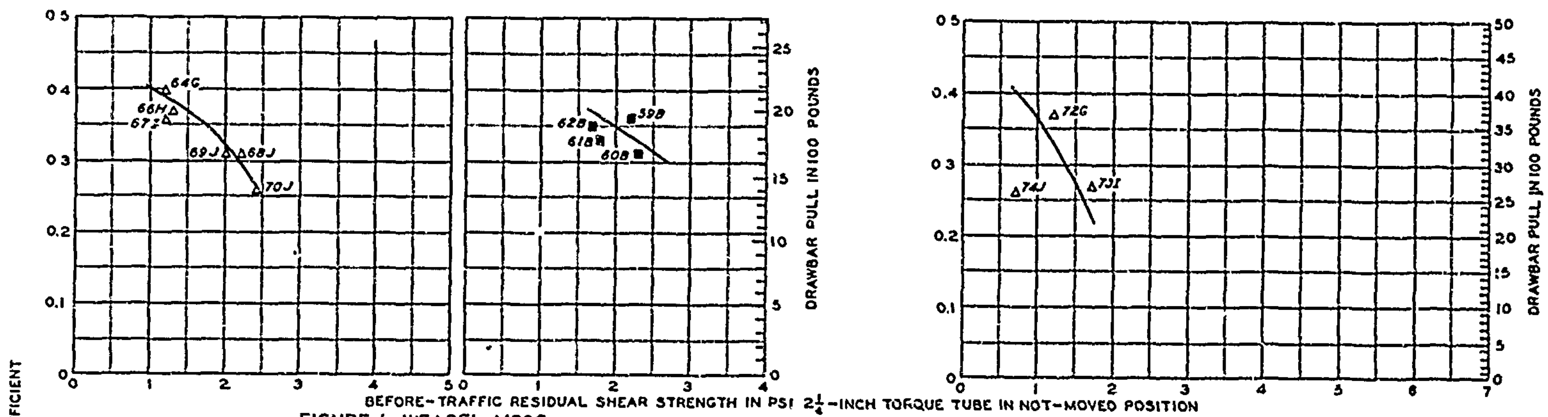
CLOSED SYMBOLS INDICATE COARSE-GRAINED SNOW

TRACKED VEHICLE TOWING TESTS

BEFORE-TRAFFIC

$2\frac{1}{4}$-INCH TORQUE TUBE

INITIAL SHEAR STRENGTH (NOT-MOVED POSITION) VS MAXIMUM DRAWBAR PULL

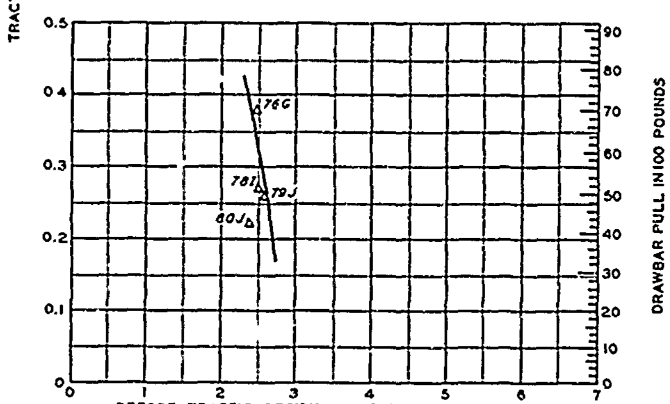


BEFORE-TRAFFIC RESIDUAL SHEAR STRENGTH IN PSI $2\frac{1}{4}$-INCH TORQUE TUBE IN NOT-MOVED POSITION

FIGURE 1. WEASEL M29C

FIGURE 2. OTTER M76

0- TO 12-INCH DEPTH



BEFORE-TRAFFIC RESIDUAL SHEAR STRENGTH IN PSI
$2\frac{1}{4}$-INCH TORQUE TUBE IN NOT-MOVED POSITION

FIGURE 3. STD D6 TRACTOR (30-IN. TRACK)

0- TO 12-INCH DEPTH

LEGEND

□ WET SNOW (W_d)
○ MOIST SNOW (W_c)
△ DRY SNOW (W_a)

NUMBERS NEAR PLOTTED POINTS REFER TO ITEM NUMBERS AND LETTERS REFER TO 1955 TEST SITES

OPEN SYMBOLS INDICATE FINE-GRAINED SNOW

CLOSED SYMBOLS INDICATE COARSE-GRAINED SNOW

TRACKED VEHICLE TOWING TESTS

BEFORE-TRAFFIC
$2\frac{1}{4}$-INCH TORQUE TUBE
RESIDUAL SHEAR STRENGTH
(NOT-MOVED POSITION) VS
MAXIMUM DRAWBAR PULL

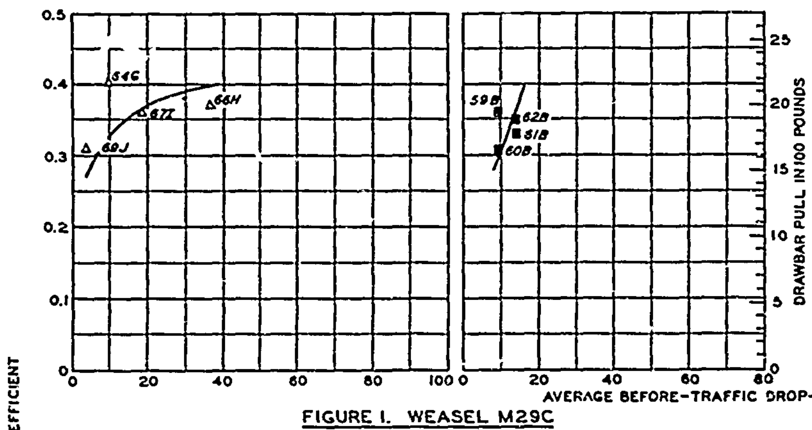


FIGURE I. WEASEL M29C

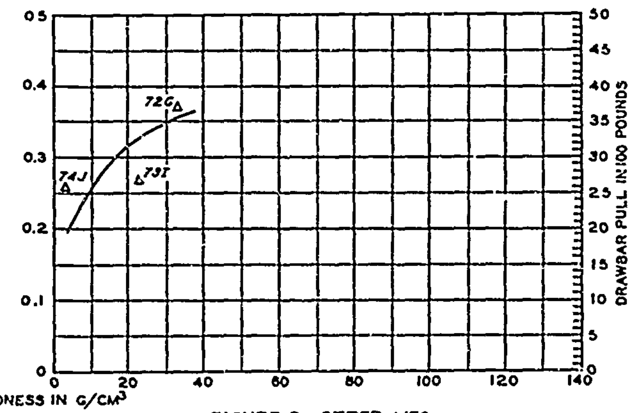
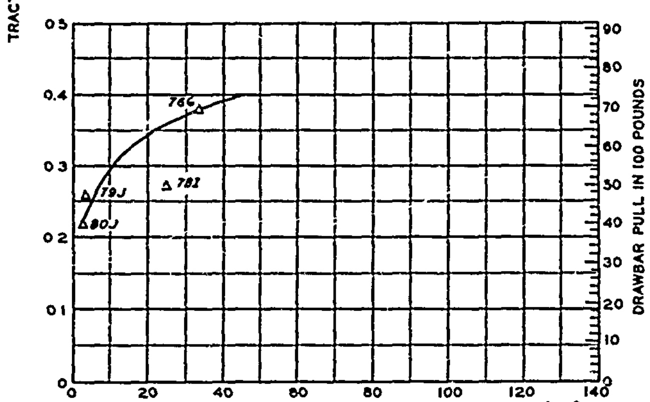


FIGURE 2. OTTER M76

0- TO 12-INCH DEPTH



AVERAGE BEFORE-TRAFFIC DROP-CONE HARDNESS IN G/CM³

FIGURE 3. STD D6 TRACTOR (30-IN. TRACK)

0- TO 12-INCH DEPTH

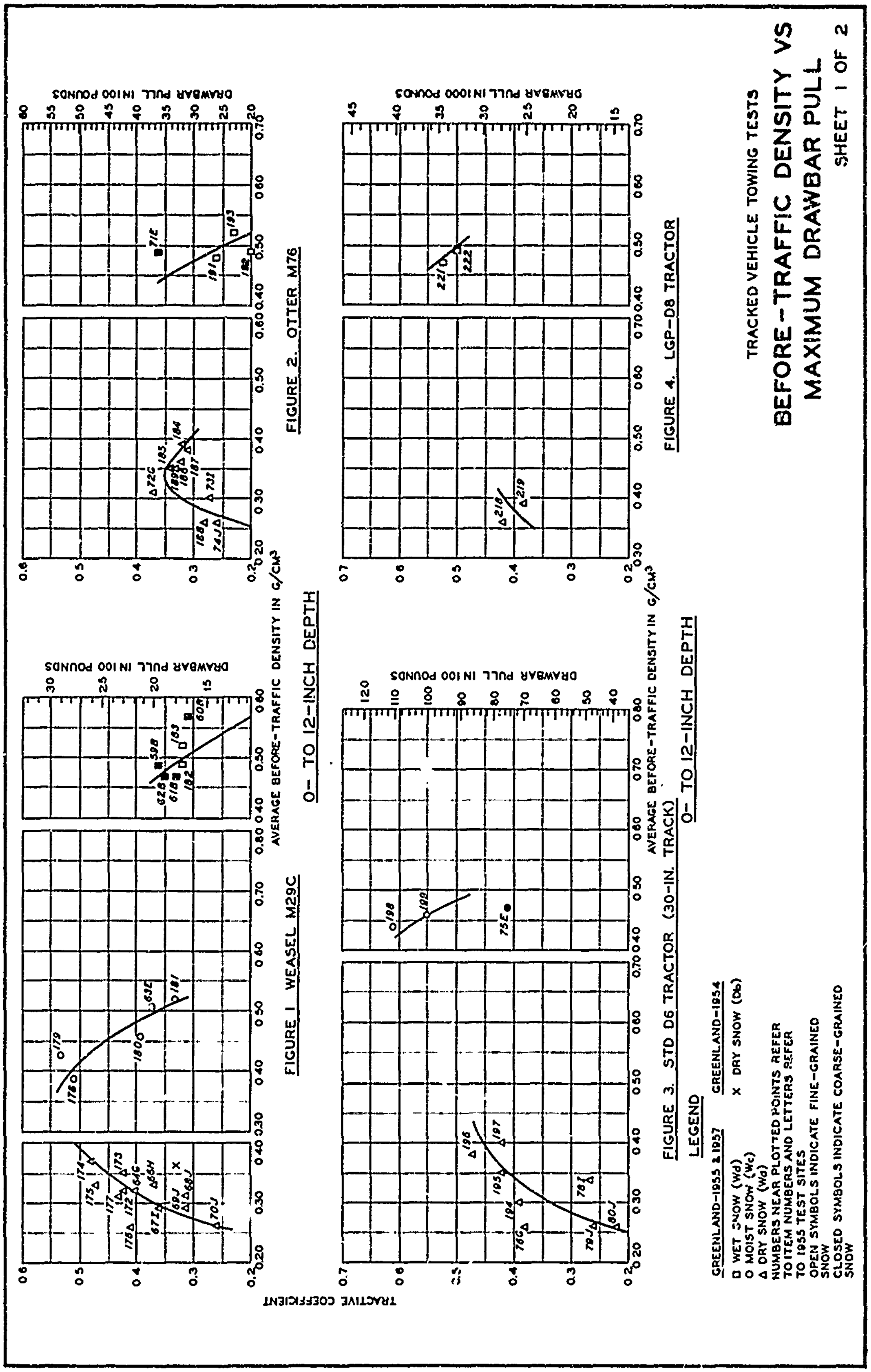
LEGEND

□ WET SNOW (Wd)
○ MOIST SNOW (Wc)
△ DRY SNOW (Wa)

NUMBERS NEAR PLOTTED POINTS REFER TO ITEM NUMBERS AND LETTERS REFER TO 1955 TEST SITES
OPEN SYMBOLS INDICATE FINE-GRAINED SNOW
CLOSED SYMBOLS INDICATE COARSE-GRAINED SNOW

TRACKED VEHICLE TOWING TESTS

BEFORE-TRAFFIC DROP-CONE HARDNESS VS MAXIMUM DRAWBAR PULL


TRACKED VEHICLE TOWING TESTS
BEFORE-TRAFFIC DENSITY VS MAXIMUM DRAWBAR PULL
SHEET 1 OF 2
FIGURE 1. WEASEL M29C
FIGURE 2. OTTER M76
FIGURE 3. STD D6 TRACTOR (30-IN. TRACK)
FIGURE 4. LGP-D8 TRACTOR
0- TO 12-INCH DEPTH
AVERAGE BEFORE-TRAFFIC DENSITY IN G/CM³
TRACTIVE COEFFICIENT
DRAWBAR PULL IN 100 POUNDS
DRAWBAR PULL IN 1000 POUNDS
LEGEND
GREENLAND-1955 & 1957
□ WET SNOW (Wd)
O MOIST SNOW (Wc)
Δ DRY SNOW (Wd)
GREENLAND-1954
X DRY SNOW (Db)
NUMBERS NEAR PLOTTED POINTS REFER TO ITEM NUMBERS AND LETTERS REFER TO 1955 TEST SITES
OPEN SYMBOLS INDICATE FINE-GRAINED SNOW
CLOSED SYMBOLS INDICATE COARSE-GRAINED SNOW

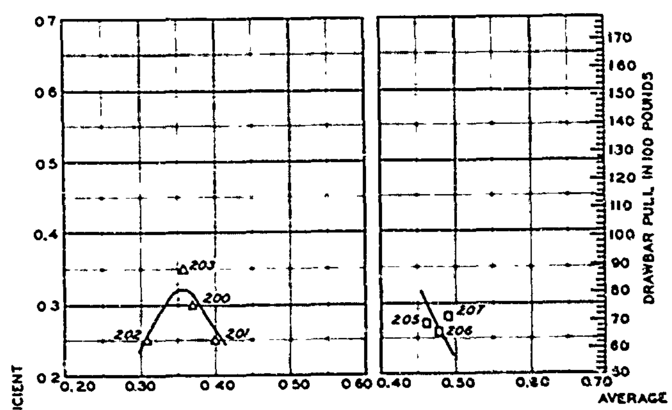


FIGURE 5 HI-SPEED TRACTOR M5A4

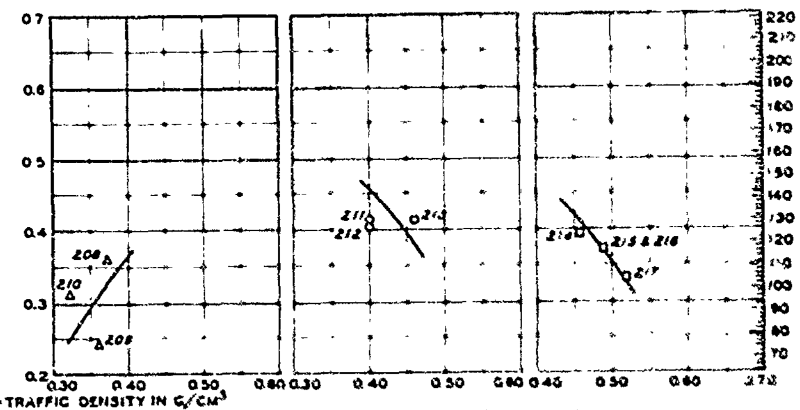


FIGURE 6 HI-SPEED TRACTOR M4

0- TO 12-INCH DEPTH

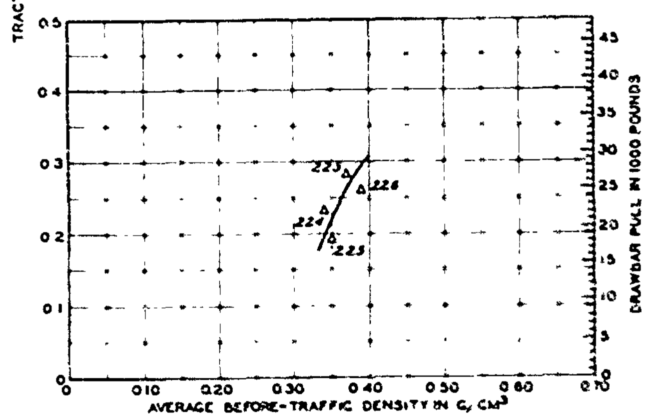


FIGURE 7 MEDIUM TANK M48

0- TO 12-INCH DEPTH

LEGEND

□ WET SNOW (Ww)
○ MOIST SNOW (Wm)
△ DRY SNOW (Wd)

NUMBERS NEAR PLOTTED POINTS REFER TO TEST NUMBERS
OPEN SYMBOLS INDICATE FINE GRAINED SNOW
CLOSED SYMBOLS INDICATE COARSE GRAINED SNOW

TRACKED VEHICLE TOWING TESTS

BEFORE-TRAFFIC DENSITY VS MAXIMUM DRAWBAR PULL

SHEET 2 OF 2

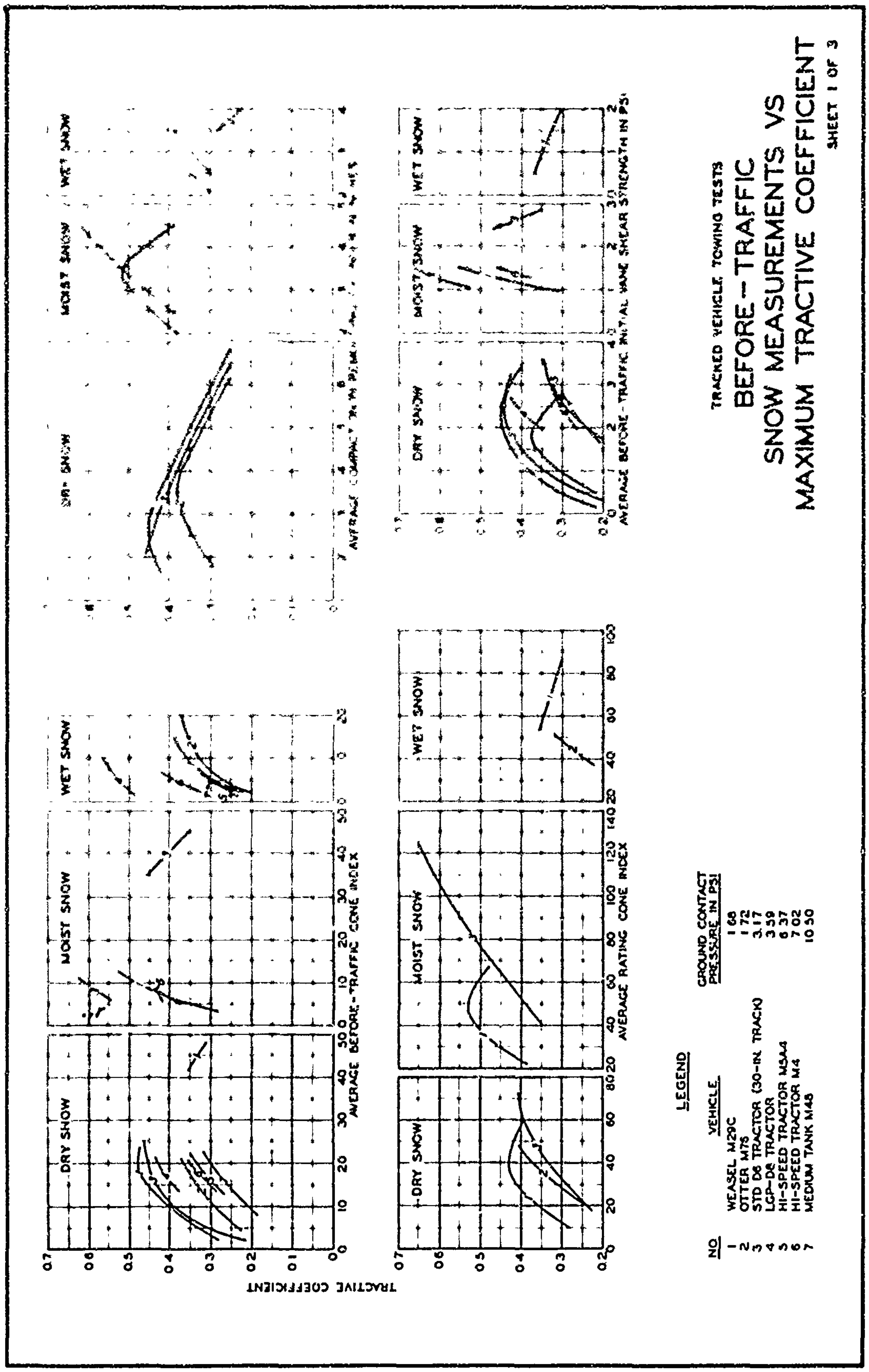
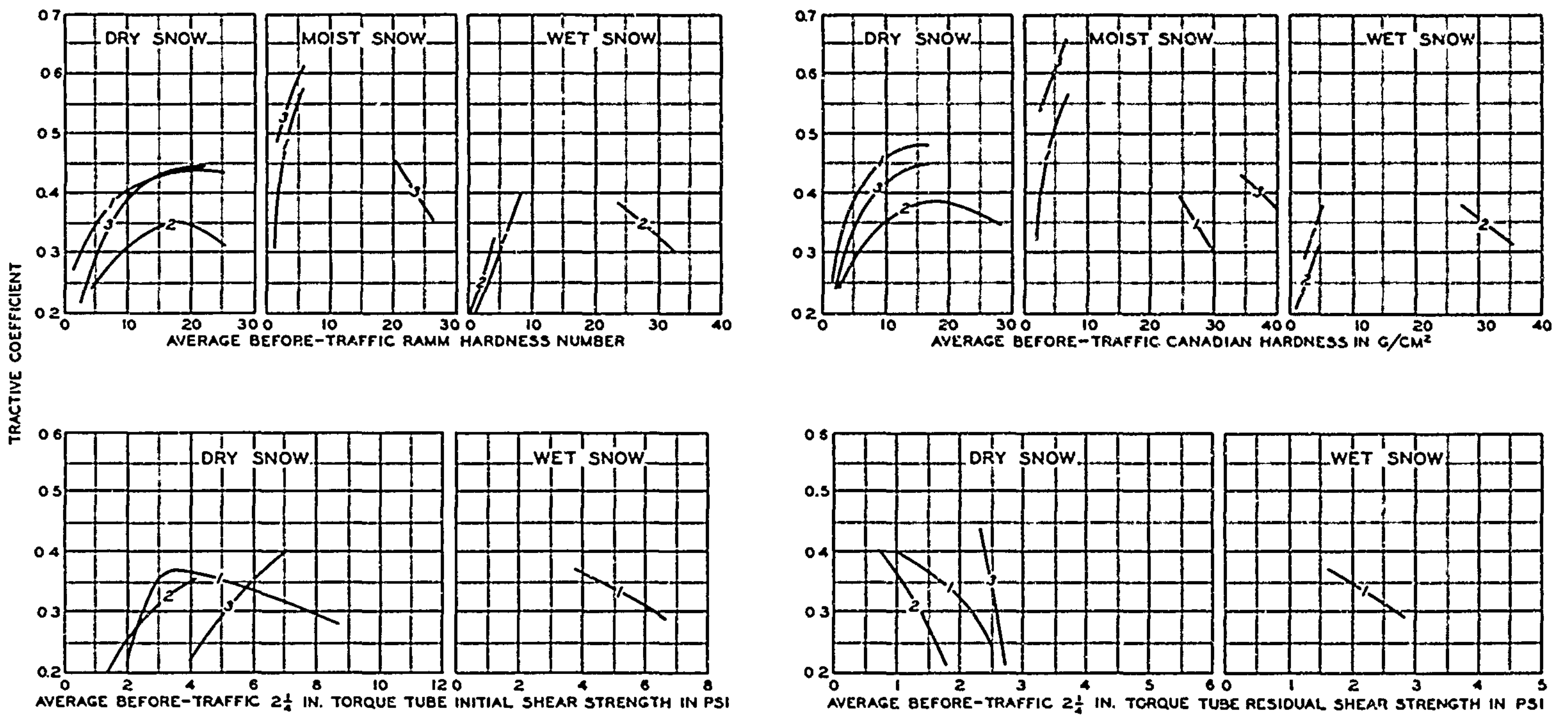

TRACKED VEHICLE TOWING TESTS
BEFORE-TRAFFIC SNOW MEASUREMENTS VS MAXIMUM TRACTIVE COEFFICIENT
SHEET 1 OF 3
DRY SNOW
MOIST SNOW
WET SNOW
TRACTIVE COEFFICIENT
AVERAGE BEFORE-TRAFFIC CONE INDEX
AVERAGE RATING CONE INDEX
AVERAGE BEFORE-TRAFFIC INITIAL VANE SHEAR STRENGTH IN PSI
LEGEND
NO
VEHICLE
GROUND CONTACT PRESSURE IN PSI
1 WEASEL M29C 1.68
2 OTTER M76 1.72
3 STD D8 TRACTOR (30-IN. TRACK) 3.17
4 LGP-D8 TRACTOR 3.59
5 HI-SPEED TRACTOR M5A4 6.37
6 HI-SPEED TRACTOR M4 7.02
7 MEDIUM TANK M48 10.50

PLATE 46



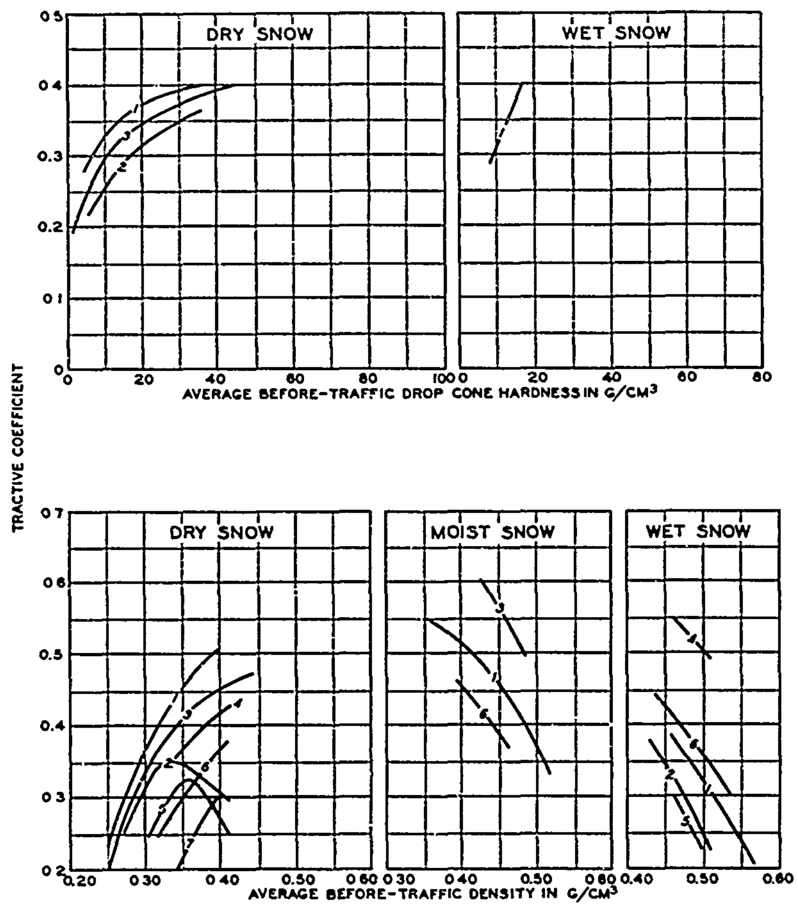
LEGEND

NO	VEHICLE	GROUND CONTACT PRESSURE IN PSI
1	WEASEL M29C	1.68
2	OTTER M76	1.72
3	STD D6 TRACTOR (30-IN. TRACK)	2.17
4	LGP-D8 TRACTOR	3.59
5	HI-SPEED TRACTOR M5A4	6.37
6	HI-SPEED TRACTOR M4	7.02
7	MEDIUM TANK M48	10.50

TRACKED VEHICLE TOWING TESTS

BEFORE-TRAFFIC
SNOW MEASUREMENTS VS
MAXIMUM TRACTIVE COEFFICIENT

SHEET 2 OF 3



LEGEND

NO	VEHICLE	GROUND CONTACT PRESSURE IN PSI
1	WEASEL M29C	1.68
2	OTTER M76	1.72
3	STD D8 TRACTOR (30-IN TRACK)	3.17
4	LGP-D8 TRACTOR	3.59
5	HI-SPEED TRACTOR M5A4	6.37
6	HI-SPEED TRACTOR M4	7.02
7	MEDIUM TANK M48	10.50

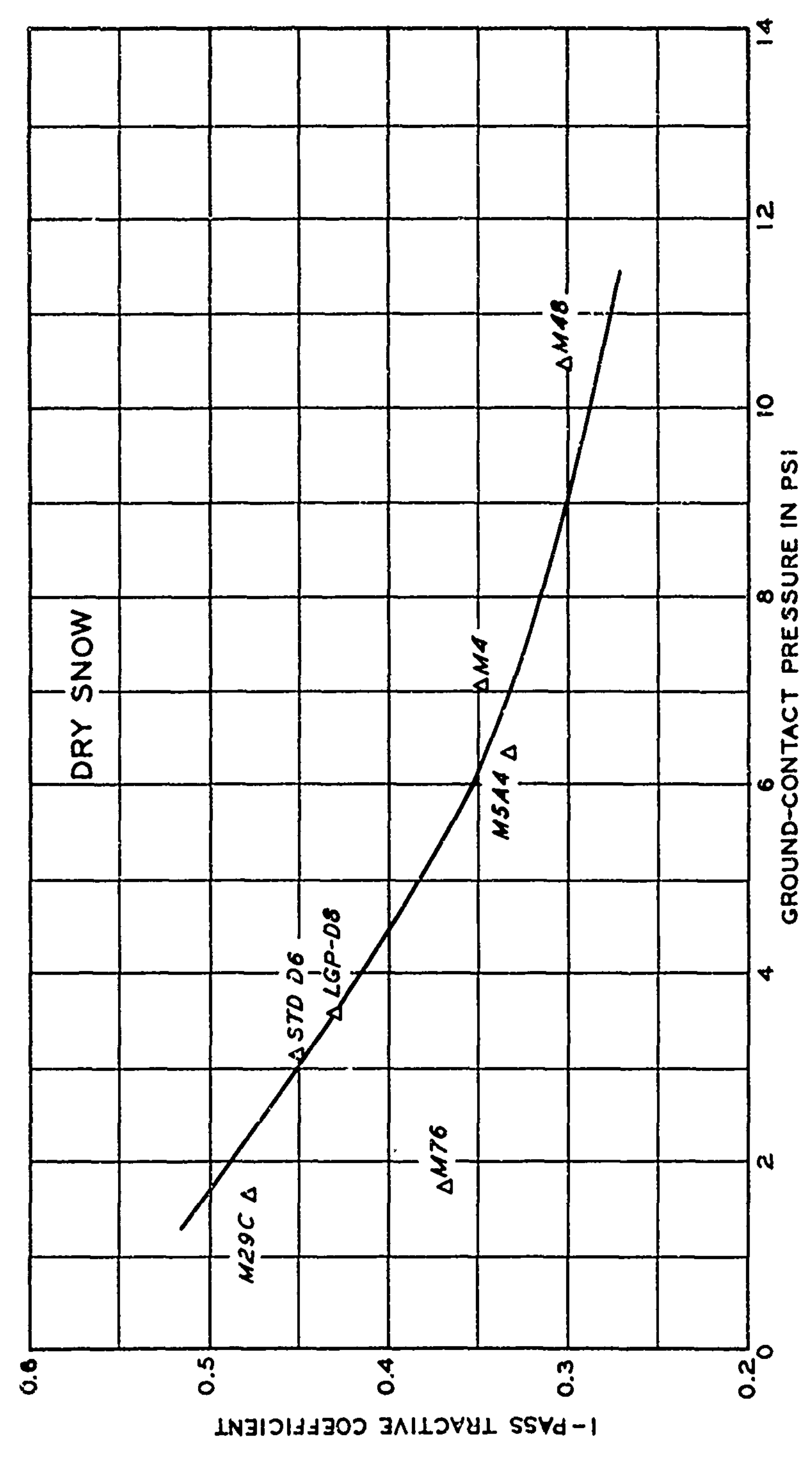
TRACKED VEHICLE TOWING TESTS

BEFORE-TRAFFIC SNOW MEASUREMENTS VS MAXIMUM TRACTIVE COEFFICIENT

SHEET 3 OF 3

PLATE 46

TRACKED VEHICLE PERFORMANCE
GROUND-CONTACT PRESSURE
VS TRACTIVE COEFFICIENT



NOTE: BEFORE-TRAFFIC CONE INDEX= 20

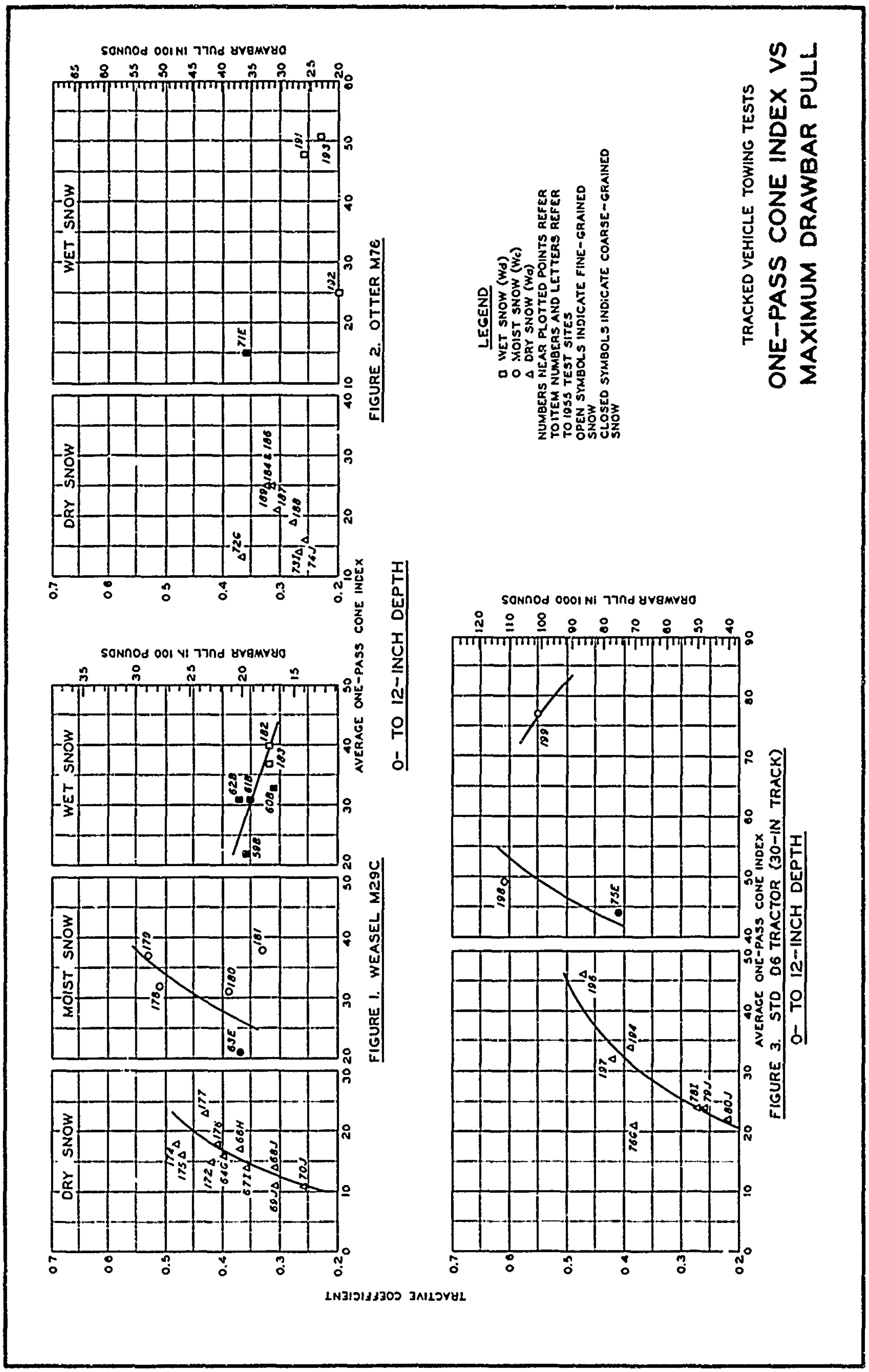

TRACKED VEHICLE TOWING TESTS
ONE-PASS CONE INDEX VS
MAXIMUM DRAWBAR PULL
LEGEND
□ WET SNOW (Wd)
○ MOIST SNOW (Wc)
Δ DRY SNOW (Wa)
NUMBERS NEAR PLOTTED POINTS REFER TO ITEM NUMBERS AND LETTERS REFER TO 1955 TEST SITES
OPEN SYMBOLS INDICATE FINE-GRAINED SNOW
CLOSED SYMBOLS INDICATE COARSE-GRAINED SNOW
FIGURE 1. WEASEL M29C
FIGURE 2. OTTER M76
0- TO 12-INCH DEPTH
FIGURE 3. STD D6 TRACTOR (30-IN TRACK)
0- TO 12-INCH DEPTH
DRY SNOW
MOIST SNOW
WET SNOW
TRACTIVE COEFFICIENT
AVERAGE ONE-PASS CONE INDEX
DRAWBAR PULL IN 100 POUNDS
DRAWBAR PULL IN 1000 POUNDS

PLATE 48

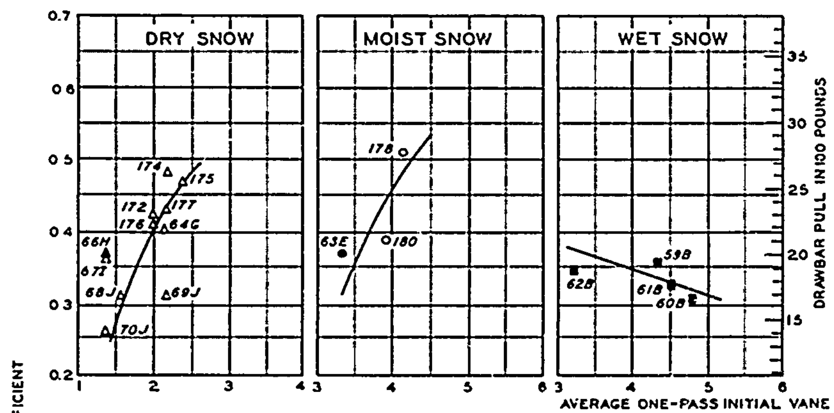


FIGURE 1. WEASEL M29C

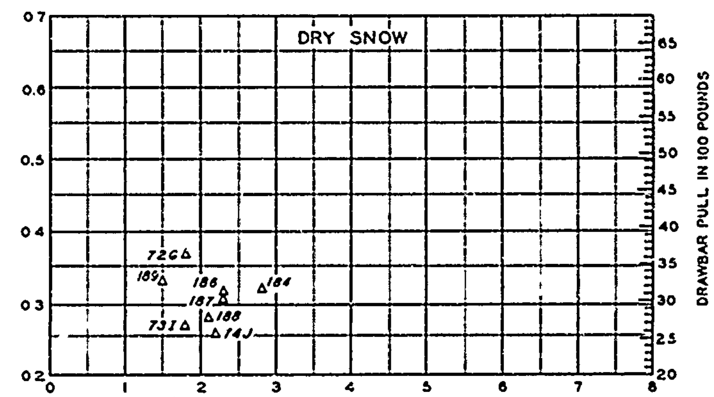


FIGURE 2. OTTER M76

0- TO 12-INCH DEPTH

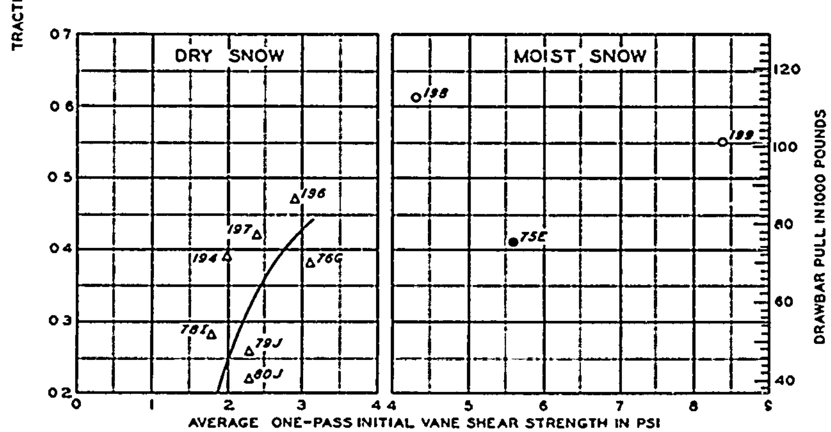


FIGURE 3. STD D6 TRACTOR (30-IN TRACK)

0- TO 12-INCH DEPTH

LEGEND

□ WET SNOW (Wd)
○ MOIST SNOW (Wc)
△ DRY SNOW (Wa)

NUMBERS NEAR PLOTTED POINTS REFER TO ITEM NUMBERS AND LETTERS REFER TO 1955 TEST SITES

OPEN SYMBOLS INDICATE FINE-GRAINED SNOW

CLOSED SYMBOLS INDICATE COARSE-GRAINED SNOW

TRACKED VEHICLE TOWING TESTS

ONE-PASS INITIAL VANE SHEAR STRENGTH VS MAXIMUM DRAWBAR PULL

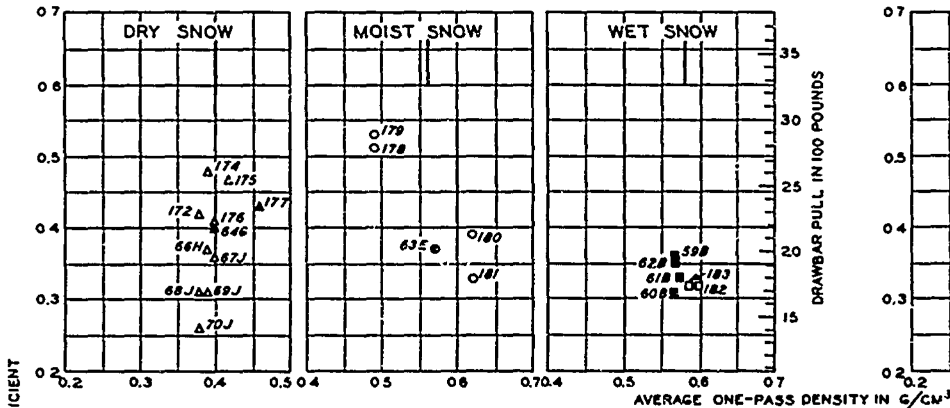


FIGURE I. WEASEL M29C

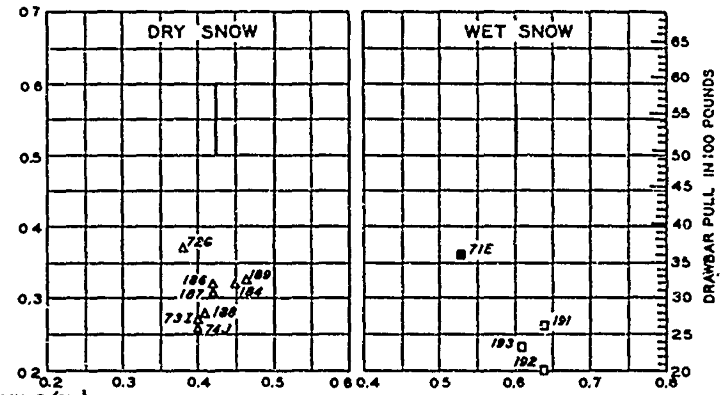


FIGURE 2. OTTER M76

0- TO 12-INCH DEPTH

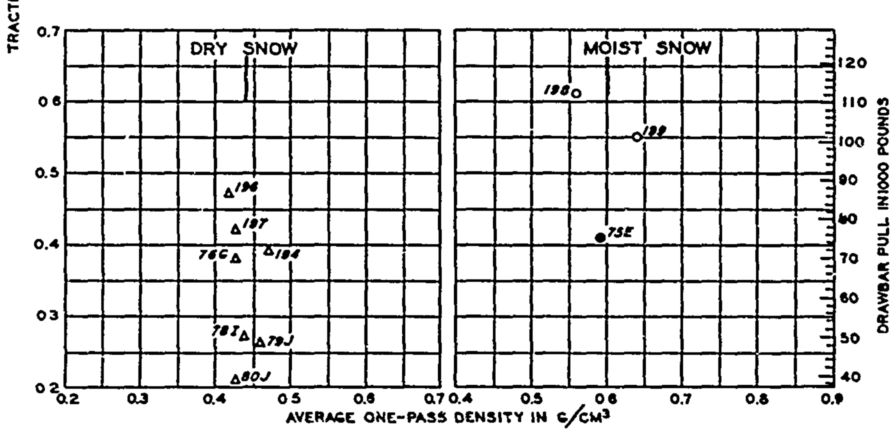


FIGURE 3. STD D6 TRACTOR (30-IN. TRACK)
0- TO 12-INCH DEPTH

LEGEND

□ WET SNOW (W_d)
○ MOIST SNOW (W_c)
△ DRY SNOW (W_o)

NUMBERS NEAR PLOTTED POINTS REFER TO ITEM NUMBERS AND LETTERS REFER TO 1955 TEST SITES
OPEN SYMBOLS INDICATE FINE-GRAINED SNOW
CLOSED SYMBOLS INDICATE COARSE-GRAINED SNOW

TRACKED VEHICLE TOWING TESTS

ONE-PASS DENSITY VS MAXIMUM DRAWBAR PULL

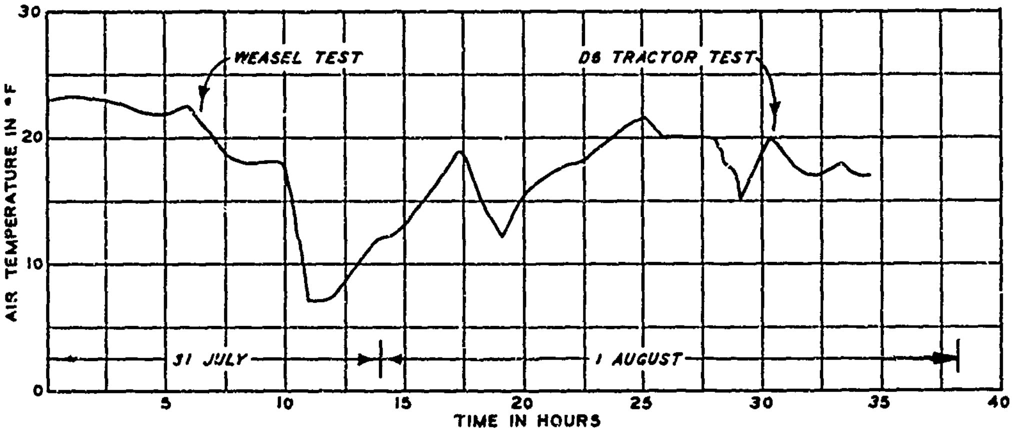


FIG. 1.

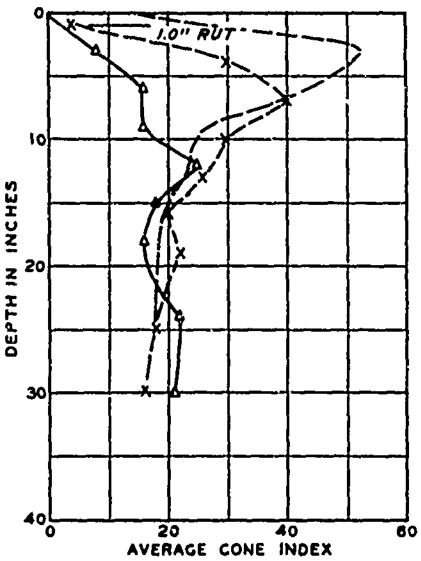


FIG. 2. WEASEL

(6-HR AGE-HARDENING)

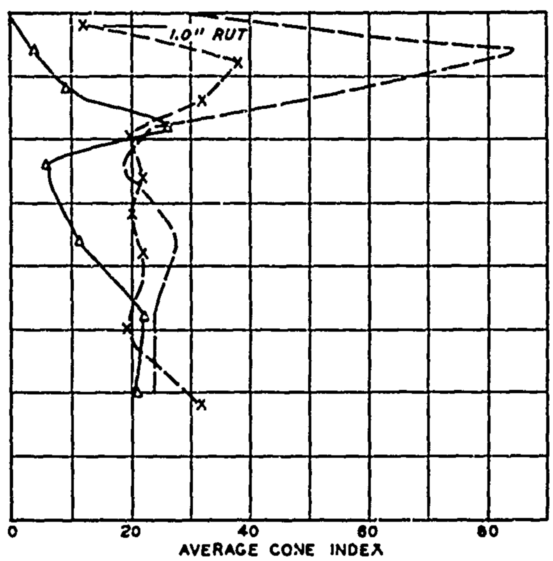


FIG. 3. D6 TRACTOR (30-IN. TRACK)

(30-HR AGE—HARDENING)

LEGEND

- ——— VIRGIN SNOW
- – – – AGE-HARDENED SNOW
- X– –X– –X AGE-HARDENED SNOW AFTER 1 PASS
- Δ DRY FINE-GRAINED SNOW

EFFECTS OF AGE-HARDENING

MILE 70

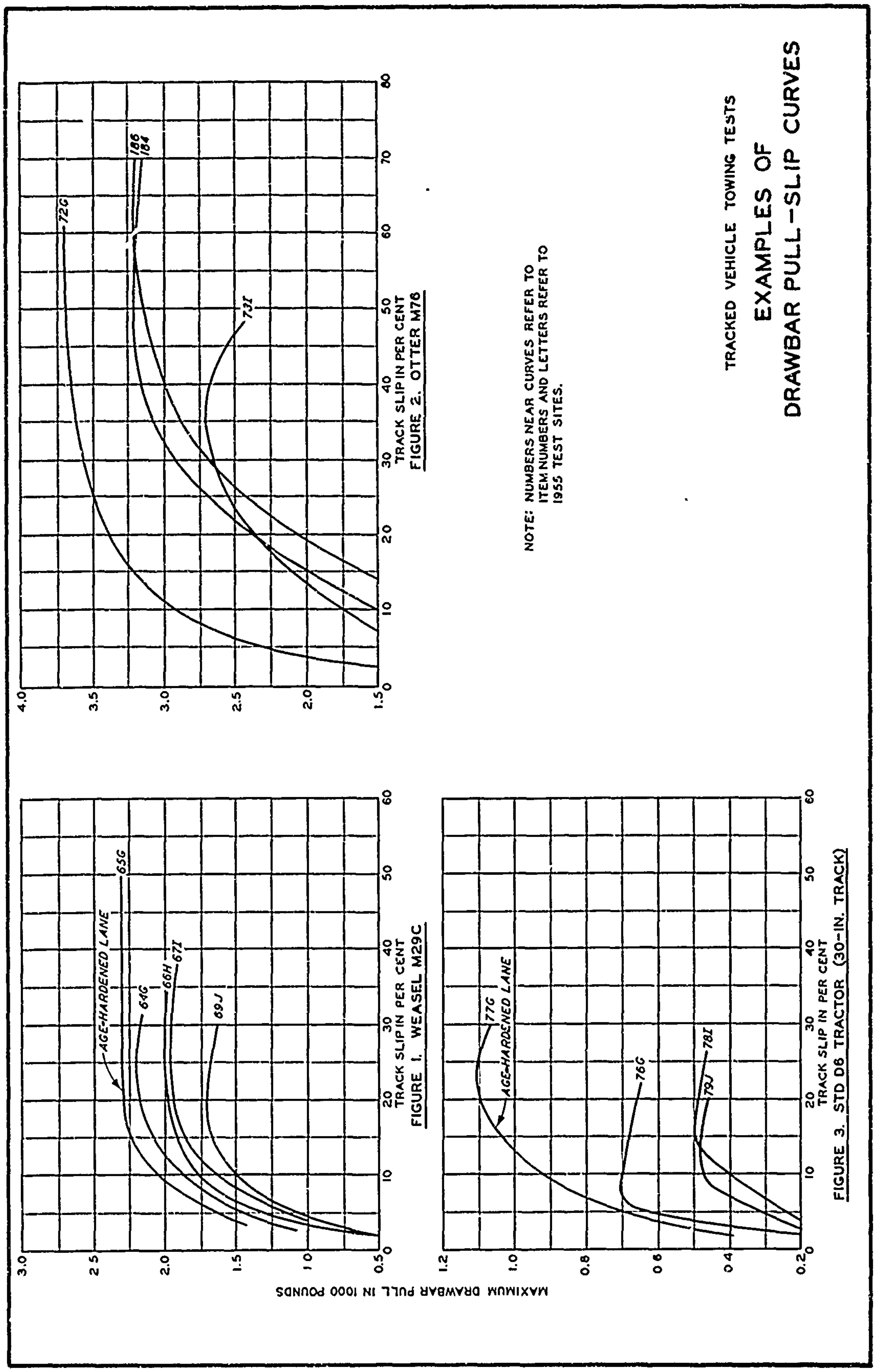

TRACKED VEHICLE TOWING TESTS
EXAMPLES OF
DRAWBAR PULL-SLIP CURVES
NOTE: NUMBERS NEAR CURVES REFER TO ITEM NUMBERS AND LETTERS REFER TO 1955 TEST SITES.
MAXIMUM DRAWBAR PULL IN 1000 POUNDS
TRACK SLIP IN PER CENT
FIGURE 1. WEASEL M29C
AGE-HARDENED LANE
64G
65G
66H
67I
69J
FIGURE 2. OTTER M76
72G
73I
184
186
FIGURE 3. STD D8 TRACTOR (30-IN. TRACK)
77G
AGE-HARDENED LANE
76G
78I
79J

PLATE 52

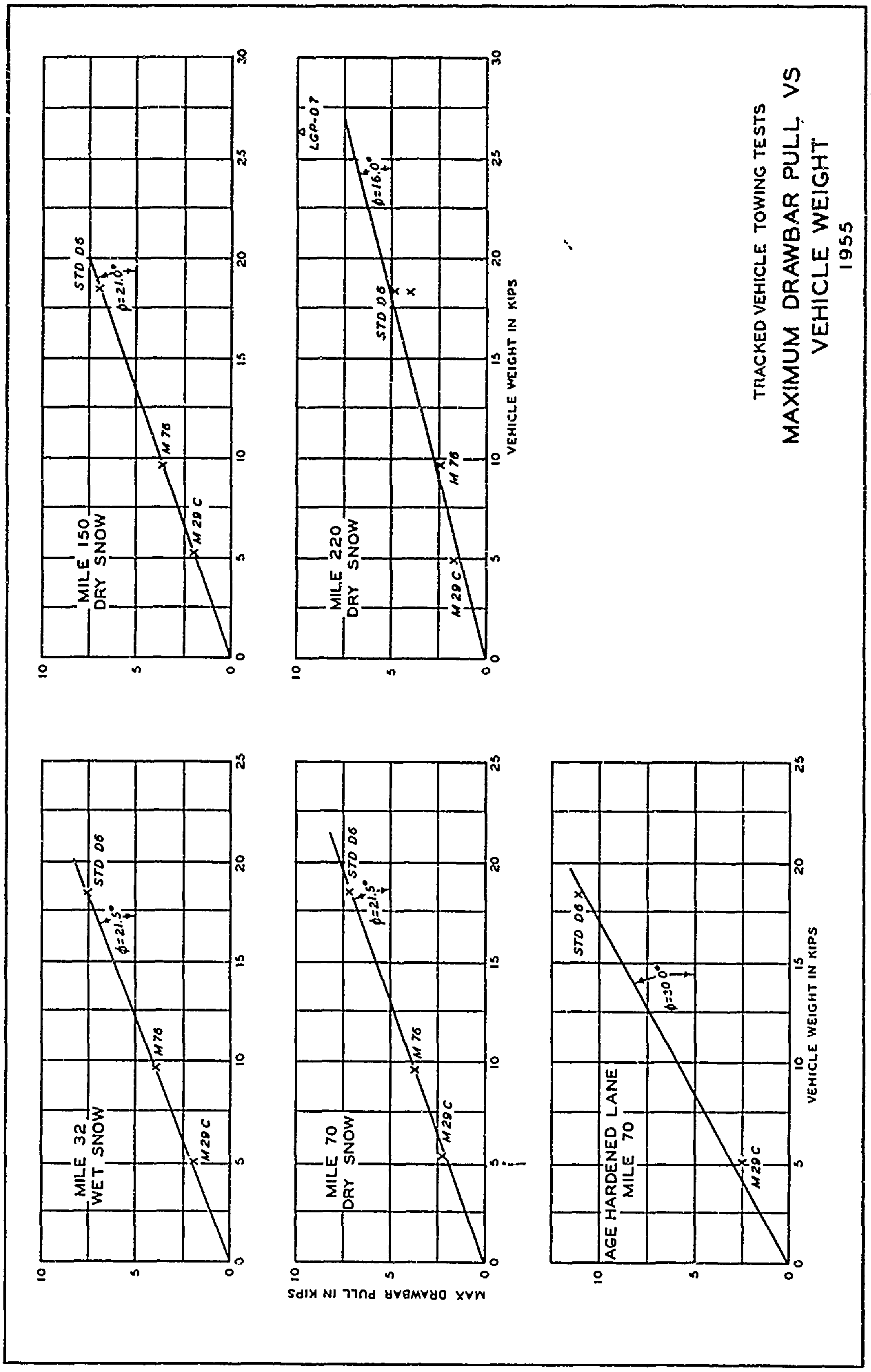

TRACKED VEHICLE TOWING TESTS
MAXIMUM DRAWBAR PULL VS
VEHICLE WEIGHT
1955
MILE 150
DRY SNOW
MILE 220
DRY SNOW
MILE 32
WET SNOW
MILE 70
DRY SNOW
AGE HARDENED LANE
MILE 70
STD D6
M 76
M 29 C
LGP-07
φ=21.0°
φ=16.0°
φ=21.5°
φ=30.0°
VEHICLE WEIGHT IN KIPS
MAX DRAWBAR PULL IN KIPS

PLATE 53

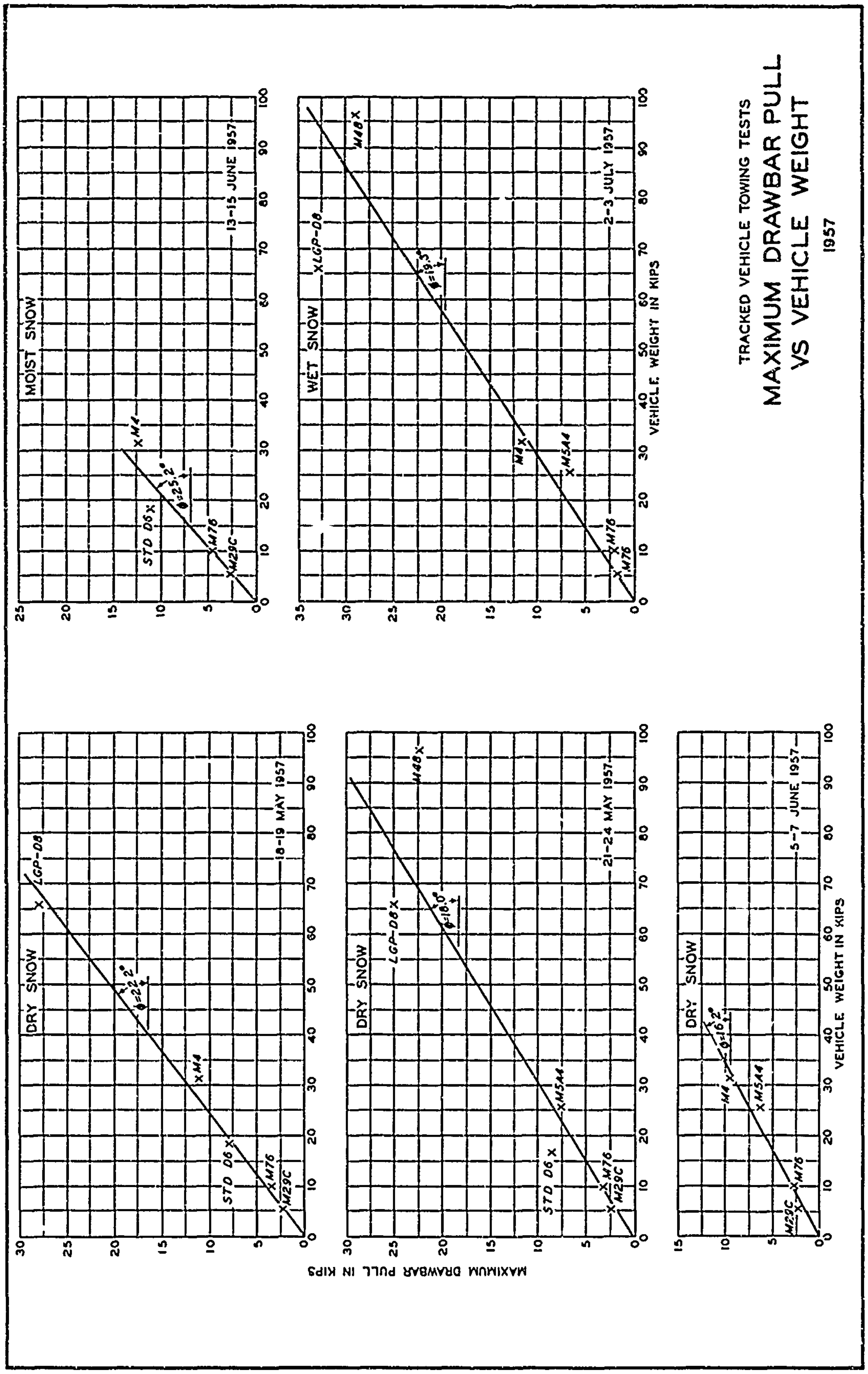
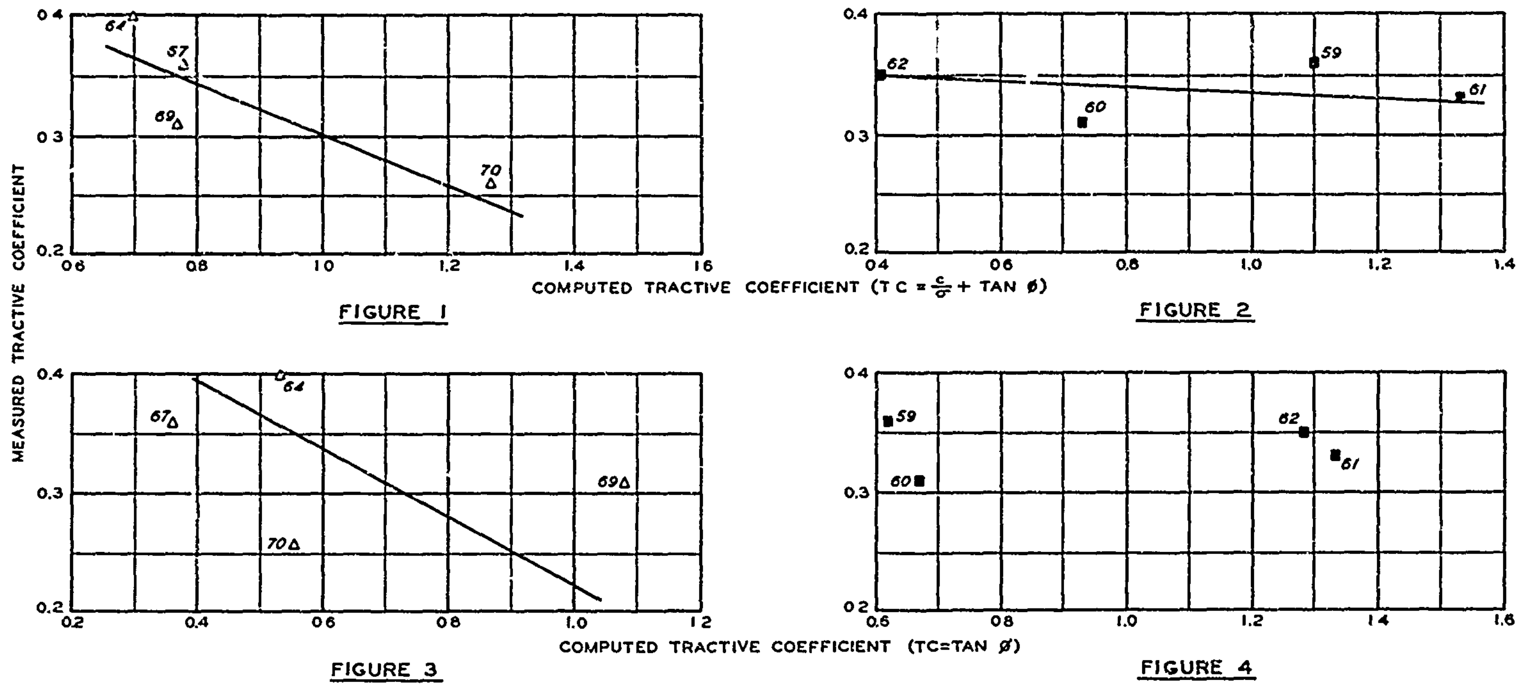

TRACKED VEHICLE TOWING TESTS
MAXIMUM DRAWBAR PULL
VS VEHICLE WEIGHT
1957
DRY SNOW
18-19 MAY 1957
DRY SNOW
21-24 MAY 1957
DRY SNOW
5-7 JUNE 1957
MOIST SNOW
13-15 JUNE 1957
WET SNOW
2-3 JULY 1957
LGP-D8
STD D6
M4
M5A4
M48
M76
M29C
ϕ=22.2°
ϕ=18.0°
ϕ=16.2°
ϕ=25.2°
ϕ=19.3°
MAXIMUM DRAWBAR PULL IN KIPS
VEHICLE WEIGHT IN KIPS

PLATE 54



LEGEND

- □ WET SNOW (wd)
- Δ DRY SNOW (wa)

OPEN SYMBOLS INDICATE FINE-GRAINED SNOW

CLOSED SYMBOLS INDICATE COARSE-GRAINED SNOW

NUMBERS NEAR PLOTTED POINTS REFER TO ITEM NUMBERS

TRACKED VEHICLE TOWING TESTS

COMPARISON OF COMPUTED AND MEASURED VEHICLE TOWING PERFORMANCE

$2\frac{1}{2}$-IN. TORQUE TUBE

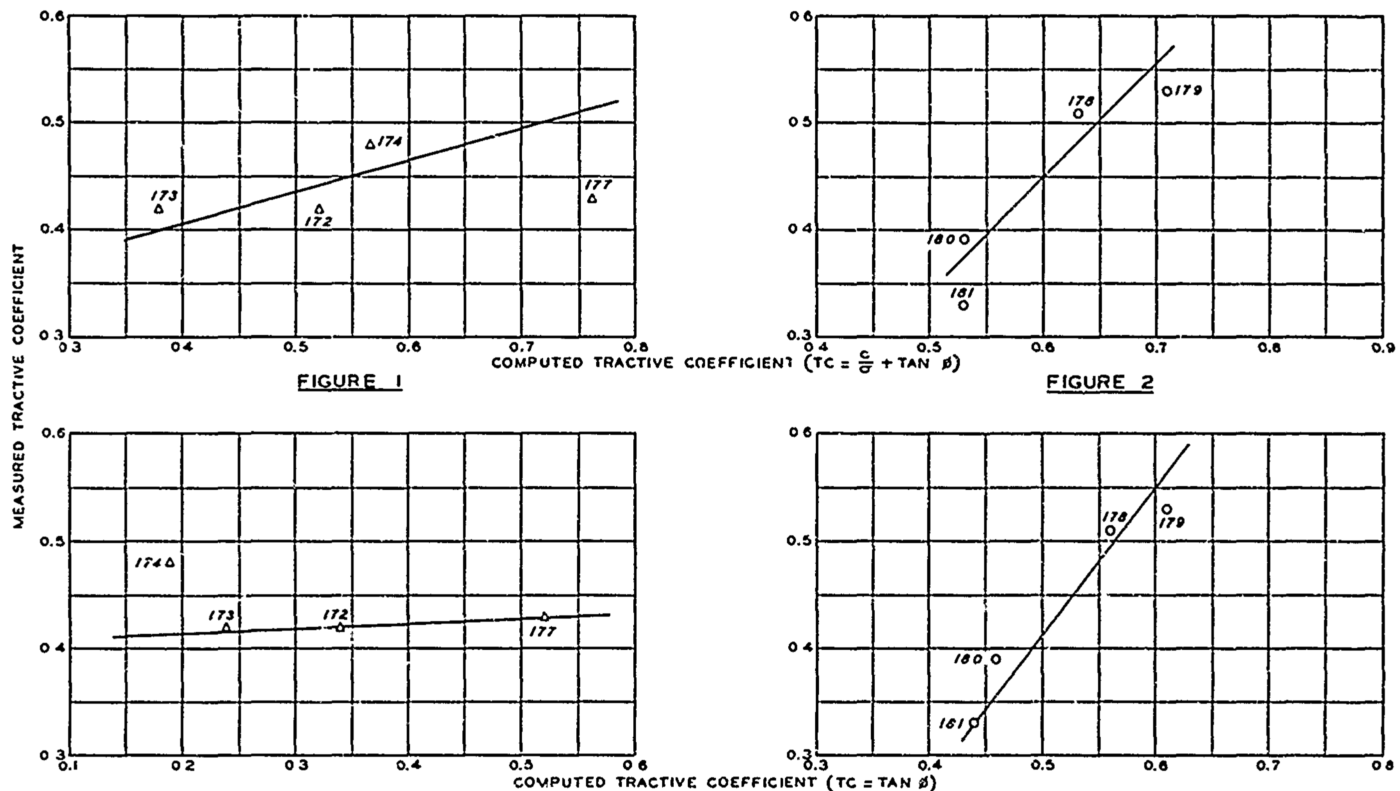


FIGURE 1

FIGURE 2

FIGURE 3

FIGURE 4

LEGEND

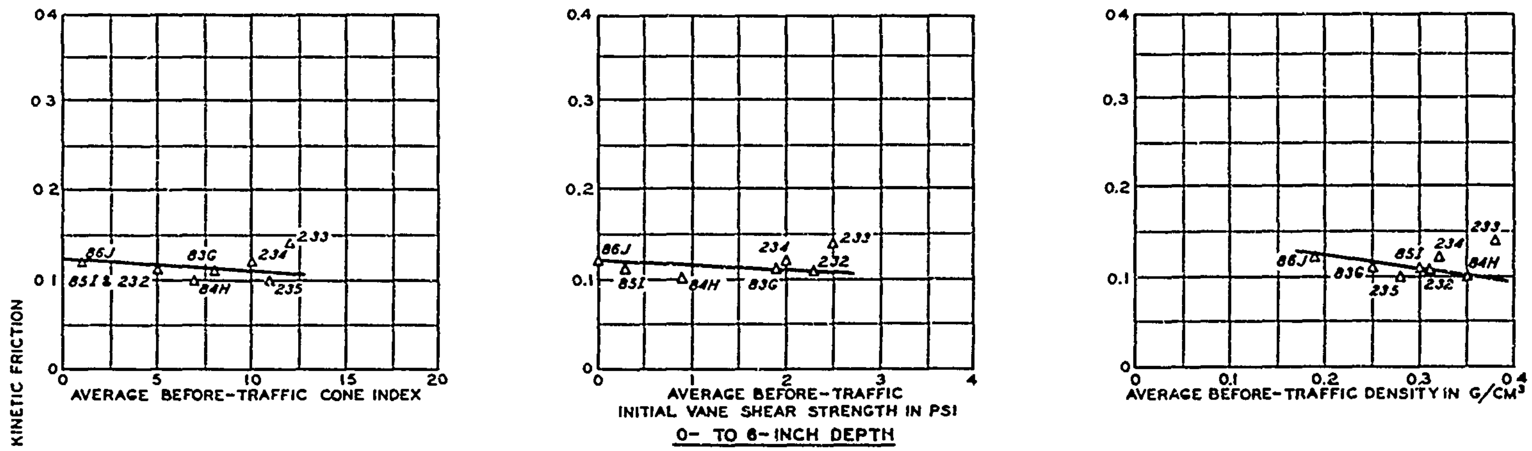
- O MOIST SNOW (Wc)
- Δ DRY SNOW (Wa)

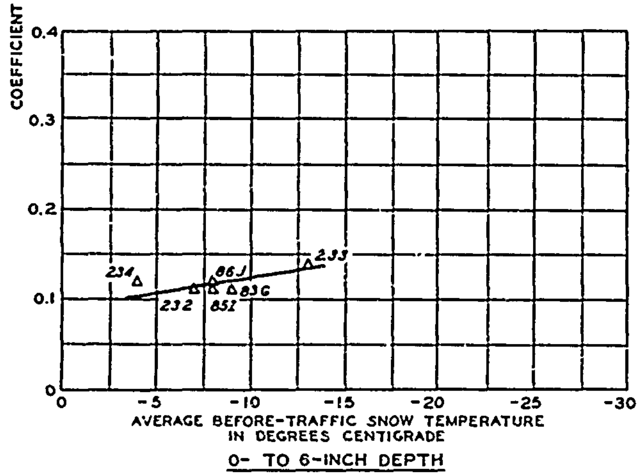
OPEN SYMBOLS INDICATE FINE-GRAINED SNOW.
NUMBERS NEAR PLOTTED POINTS REFER TO ITEM NUMBERS.

TRACKED VEHICLE TOWING TESTS

COMPARISON OF COMPUTED AND MEASURED VEHICLE TOWING PERFORMANCE

VARIABLE-LOAD SHEAR VANE





LEGEND

Δ DRY SNOW (Wa)
NUMBERS NEAR PLOTTED POINTS REFER TO ITEM NUMBERS AND LETTERS REFER TO 1955 TEST SITES.
OPEN SYMBOLS INDICATE FINE-GRAINED SNOW.
CLOSED SYMBOLS INDICATE COARSE-GRAINED SNOW.

SLED TESTS

BEFORE-TRAFFIC
SNOW MEASUREMENTS VS
KINETIC FRICTION, COMPACTED SNOW
5-TON PAYLOAD
STEEL RUNNERS

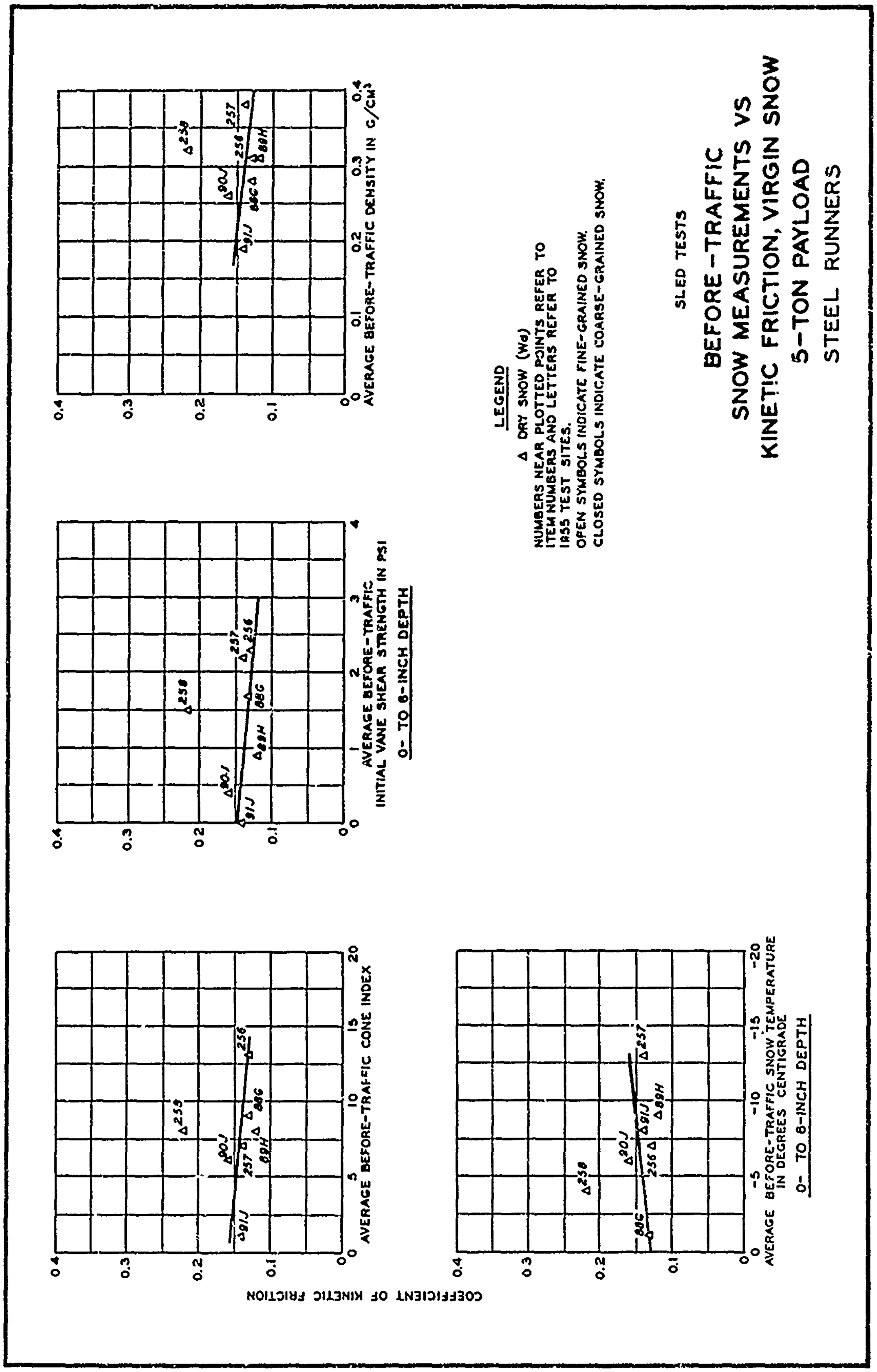
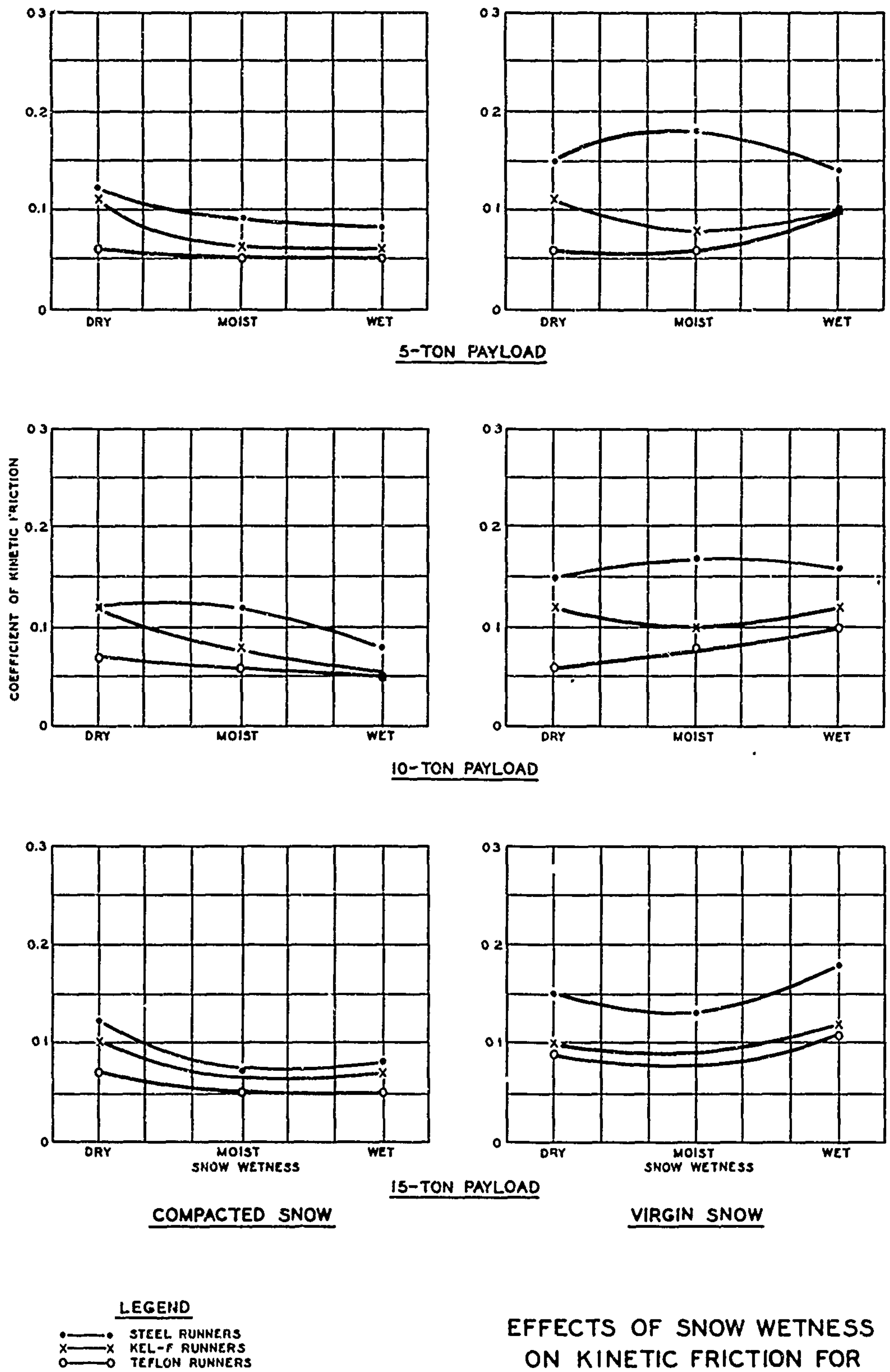

SLED TESTS
BEFORE-TRAFFIC
SNOW MEASUREMENTS VS
KINETIC FRICTION, VIRGIN SNOW
5-TON PAYLOAD
STEEL RUNNERS
LEGEND
Δ DRY SNOW (Wd)
NUMBERS NEAR PLOTTED POINTS REFER TO ITEM NUMBERS AND LETTERS REFER TO 1955 TEST SITES.
OPEN SYMBOLS INDICATE FINE-GRAINED SNOW.
CLOSED SYMBOLS INDICATE COARSE-GRAINED SNOW.
COEFFICIENT OF KINETIC FRICTION
AVERAGE BEFORE-TRAFFIC CONE INDEX
AVERAGE BEFORE-TRAFFIC SNOW TEMPERATURE IN DEGREES CENTIGRADE
0- TO 6-INCH DEPTH
AVERAGE BEFORE-TRAFFIC INITIAL VANE SHEAR STRENGTH IN PSI
0- TO 6-INCH DEPTH
AVERAGE BEFORE-TRAFFIC DENSITY IN G/CM³
258
257
256
90J
91J
88G
89H

PLATE 58



EFFECTS OF SNOW WETNESS ON KINETIC FRICTION FOR VARIOUS PAYLOADS

PLATE 59

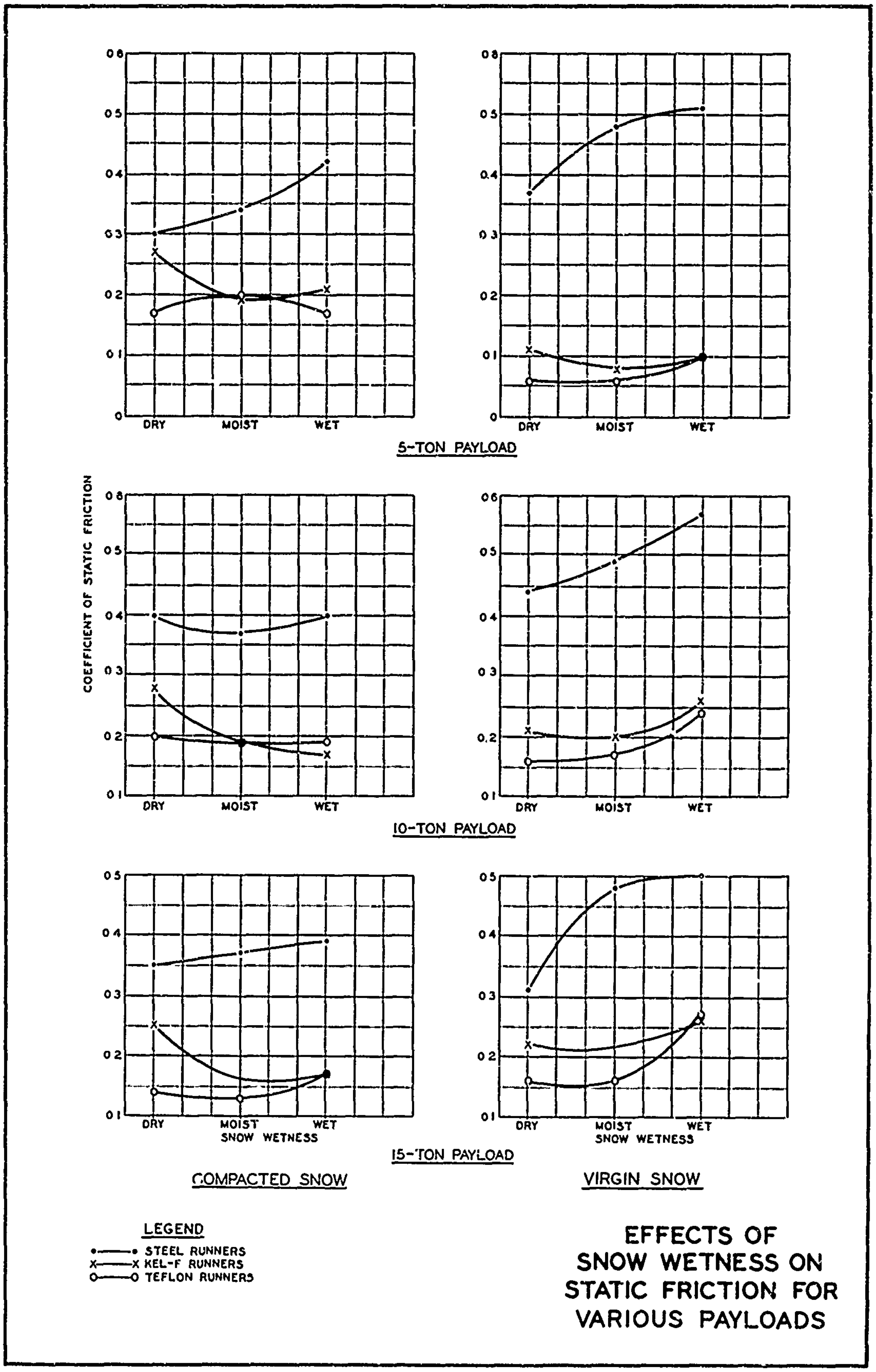
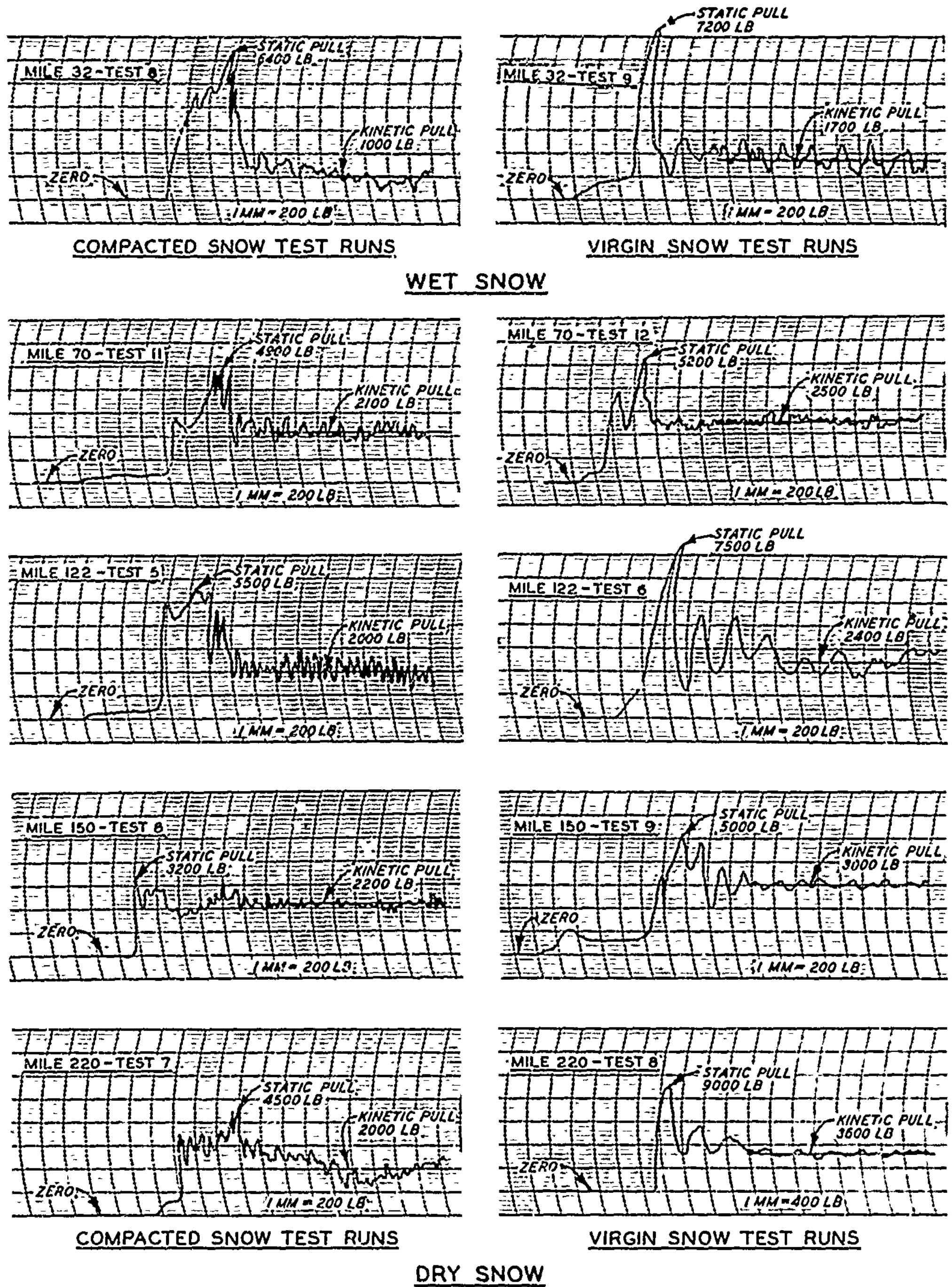

COEFFICIENT OF STATIC FRICTION
DRY
MOIST
WET
5-TON PAYLOAD
10-TON PAYLOAD
SNOW WETNESS
15-TON PAYLOAD
COMPACTED SNOW
VIRGIN SNOW
LEGEND
STEEL RUNNERS
KEL-F RUNNERS
TEFLON RUNNERS
EFFECTS OF
SNOW WETNESS ON
STATIC FRICTION FOR
VARIOUS PAYLOADS

PLATE 60



NOTE: ALL THE ABOVE TESTS WERE CONDUCTED WITH STEEL RUNNERS AND A 5-TON PAY LOAD.

1955 SLED TESTS

COMPARISON OF KINETIC AND STATIC FRICTION

PLATE 61

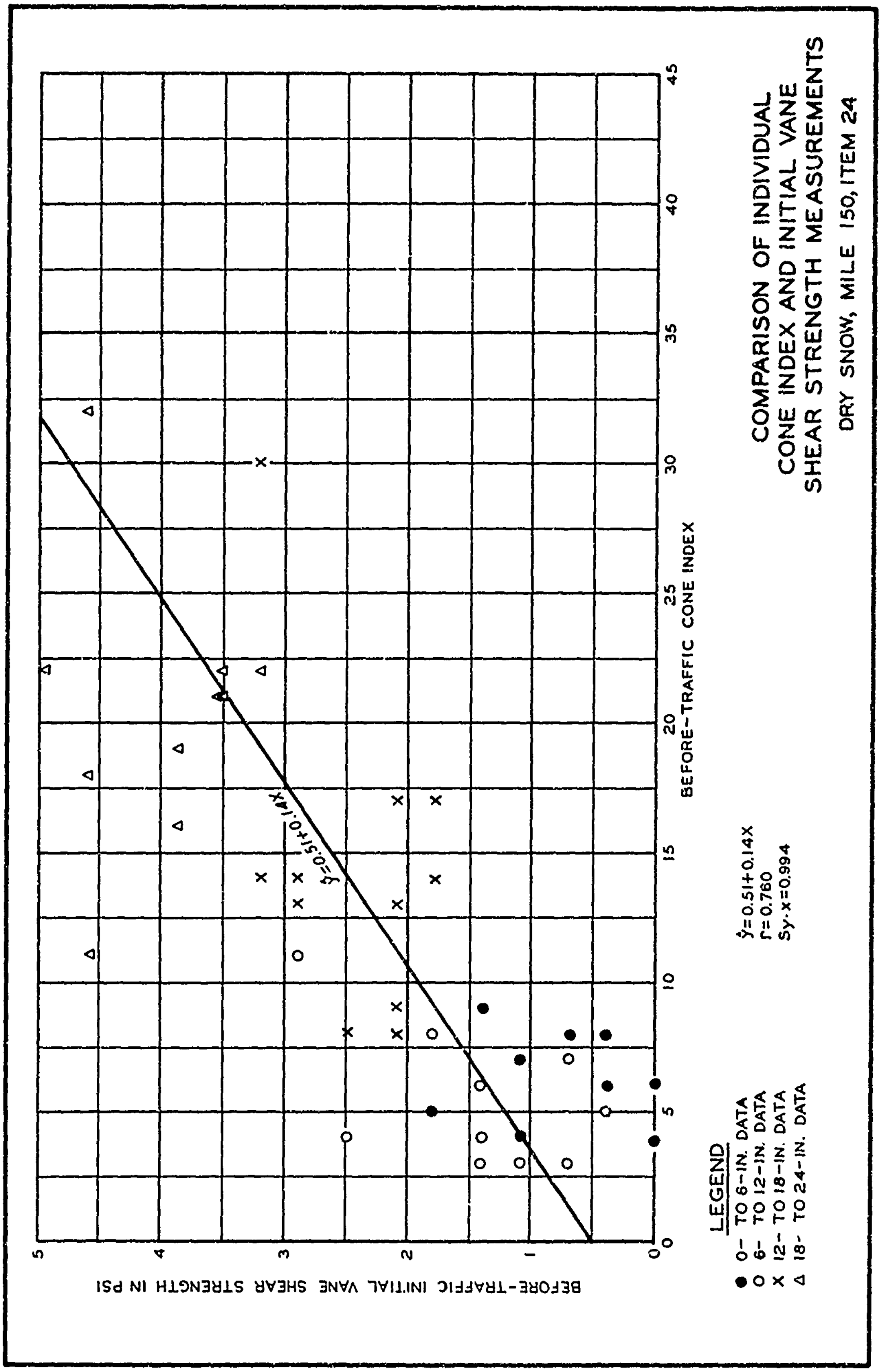
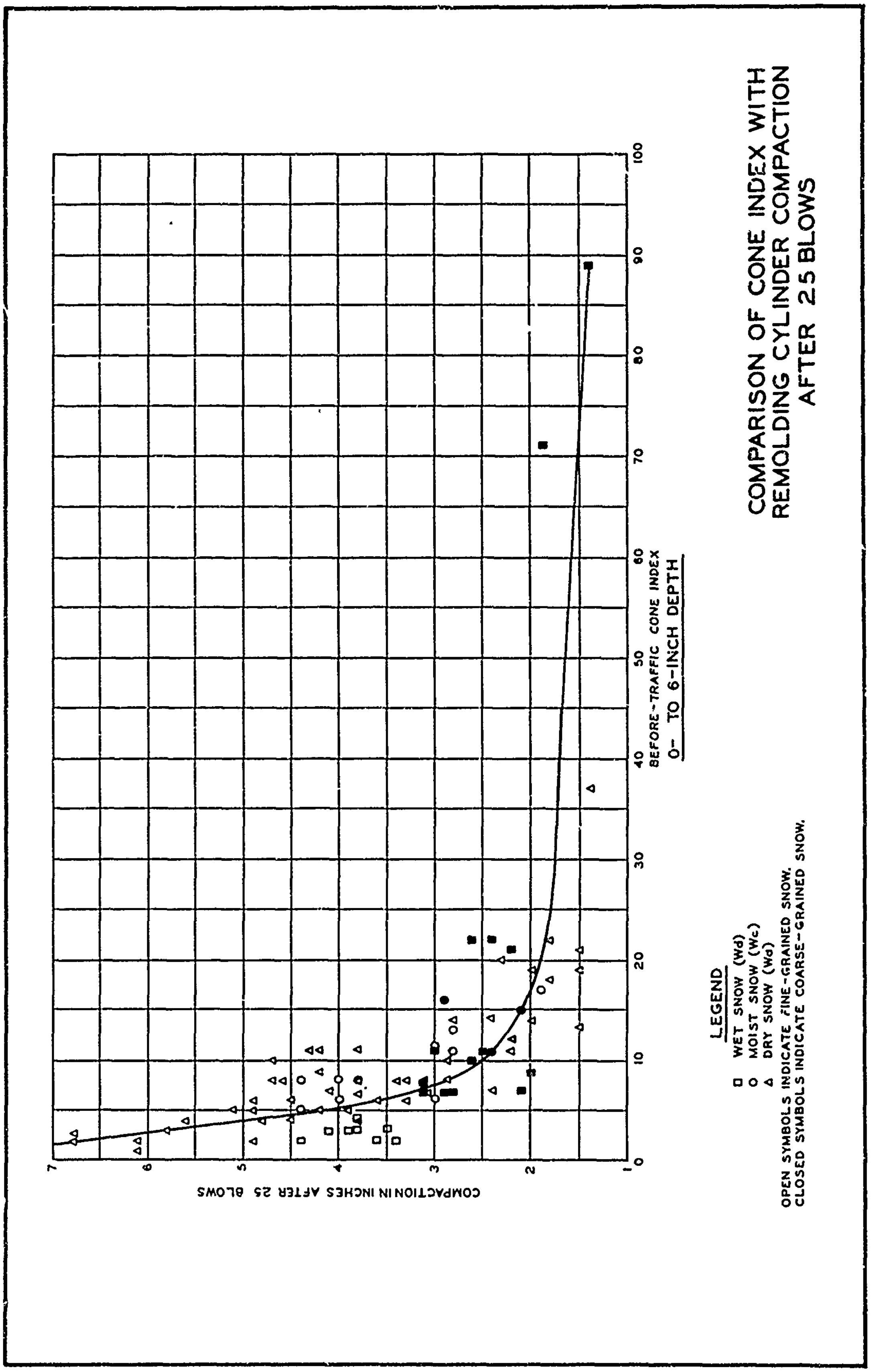
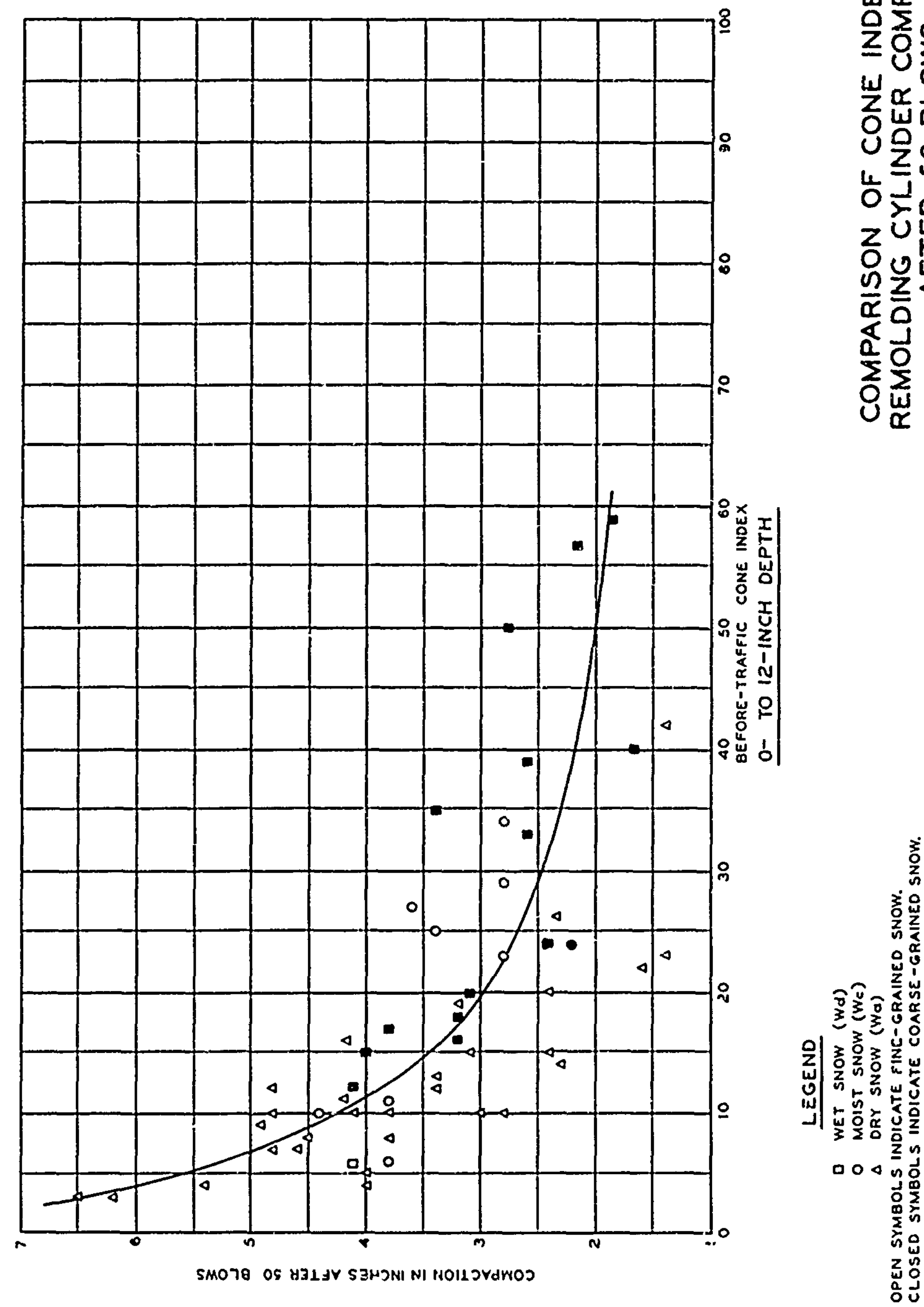

COMPARISON OF INDIVIDUAL
CONE INDEX AND INITIAL VANE
SHEAR STRENGTH MEASUREMENTS
DRY SNOW, MILE 150, ITEM 24
BEFORE-TRAFFIC CONE INDEX
BEFORE-TRAFFIC INITIAL VANE SHEAR STRENGTH IN PSI
ŷ=0.51+0.14X
ŷ=0.51+0.14X
r= 0.760
Sy.x=0.994
LEGEND
● 0- TO 6-IN. DATA
○ 6- TO 12-IN. DATA
X 12- TO 18-IN. DATA
Δ 18- TO 24-IN. DATA

PLATE 62



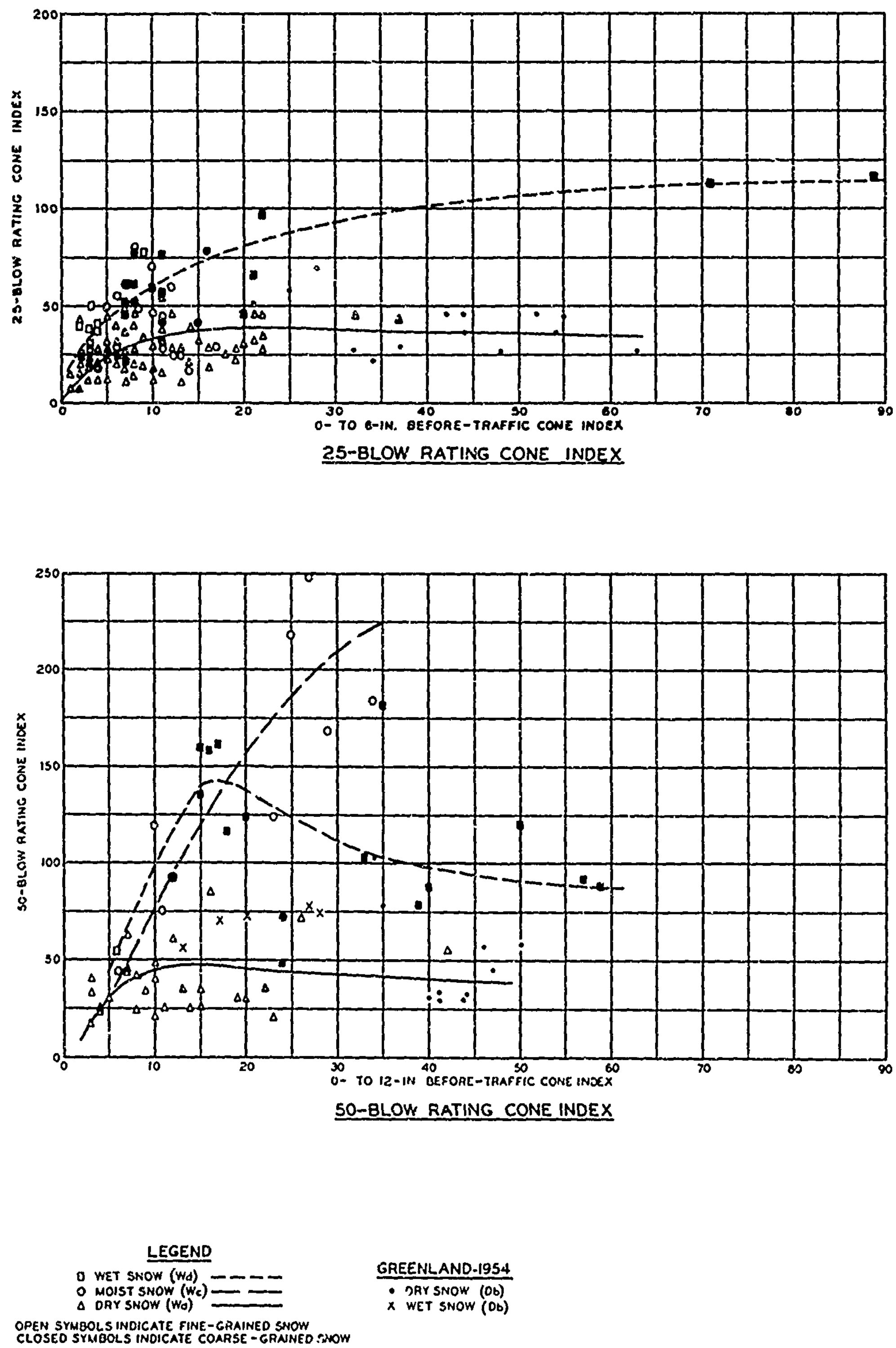
COMPARISON OF CONE INDEX WITH REMOLDING CYLINDER COMPACTION AFTER 25 BLOWS

PLATE 63

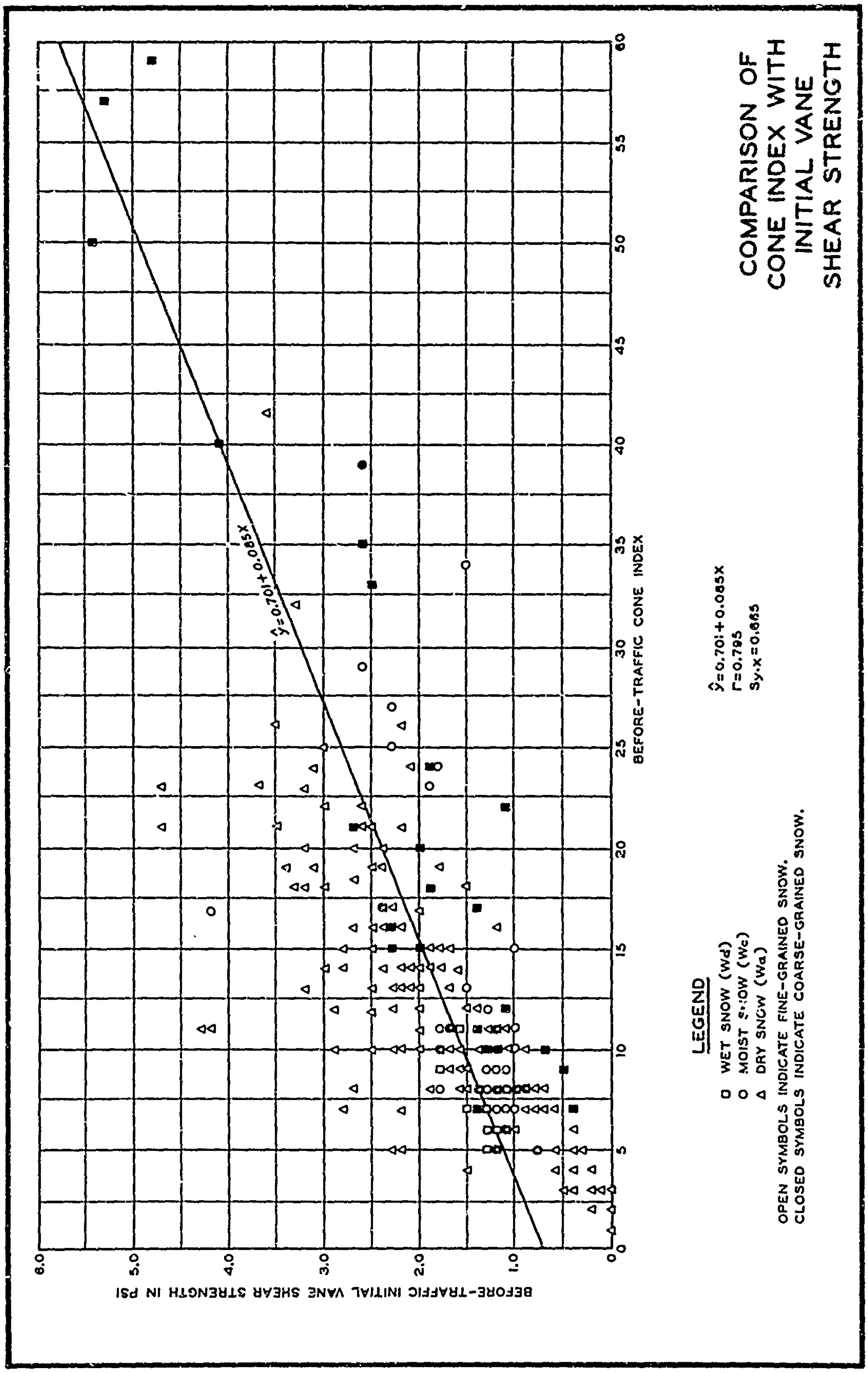


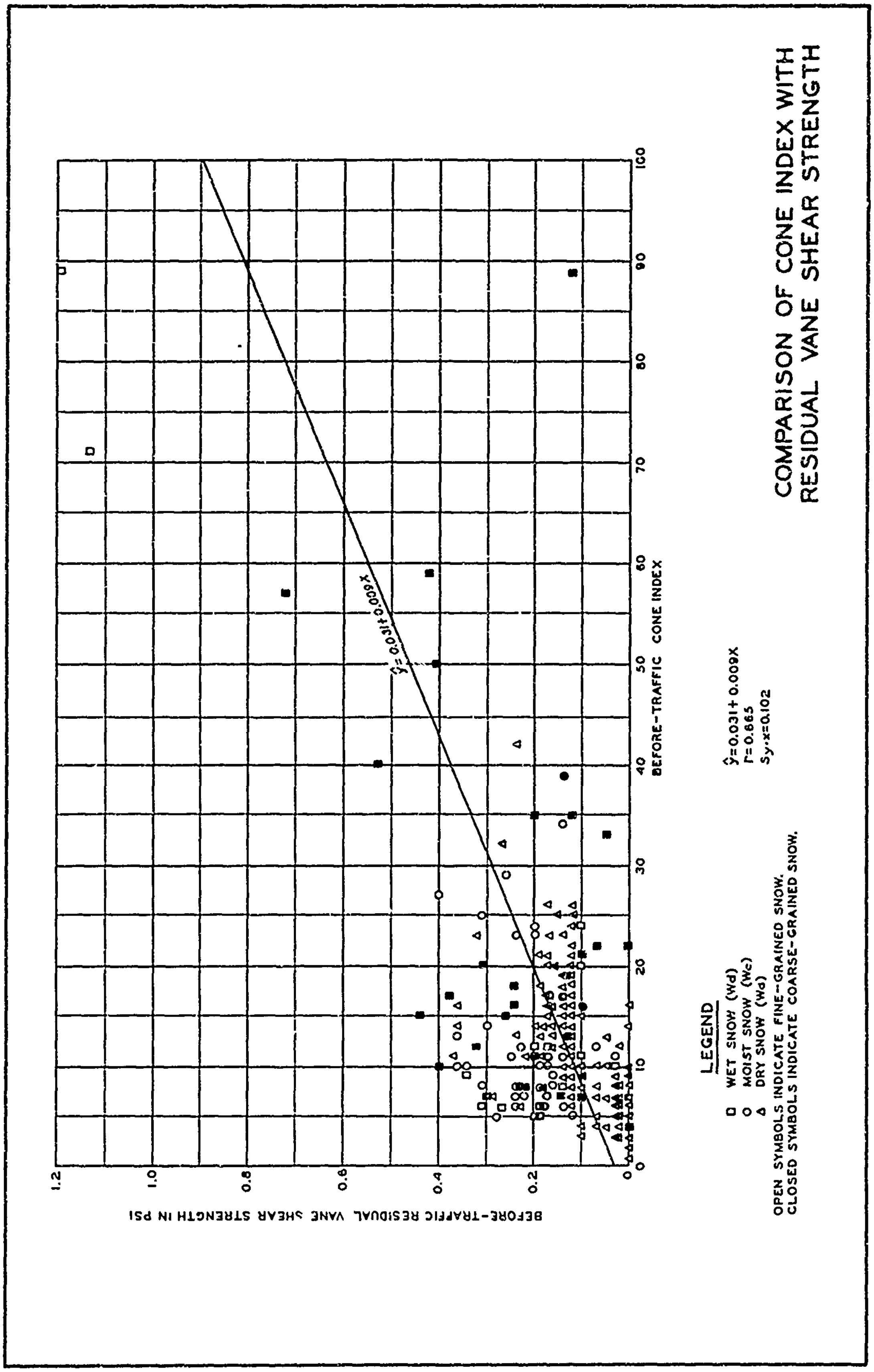
COMPARISON OF CONE INDEX WITH
REMOLDING CYLINDER COMPACTION
AFTER 50 BLOWS

PLATE 64



COMPARISON OF CONE INDEX
WITH RATING CONE INDEX


COMPARISON OF
CONE INDEX WITH
INITIAL VANE
SHEAR STRENGTH
BEFORE-TRAFFIC CONE INDEX
BEFORE-TRAFFIC INITIAL VANE SHEAR STRENGTH IN PSI
ŷ=0.701+0.085X
ŷ=0.701+0.085X
r=0.795
Sy.x=0.665
LEGEND
□ WET SNOW (Wd)
○ MOIST SNOW (Wc)
△ DRY SNOW (Wa)
OPEN SYMBOLS INDICATE FINE-GRAINED SNOW.
CLOSED SYMBOLS INDICATE COARSE-GRAINED SNOW.



COMPARISON OF CONE INDEX WITH RESIDUAL VANE SHEAR STRENGTH

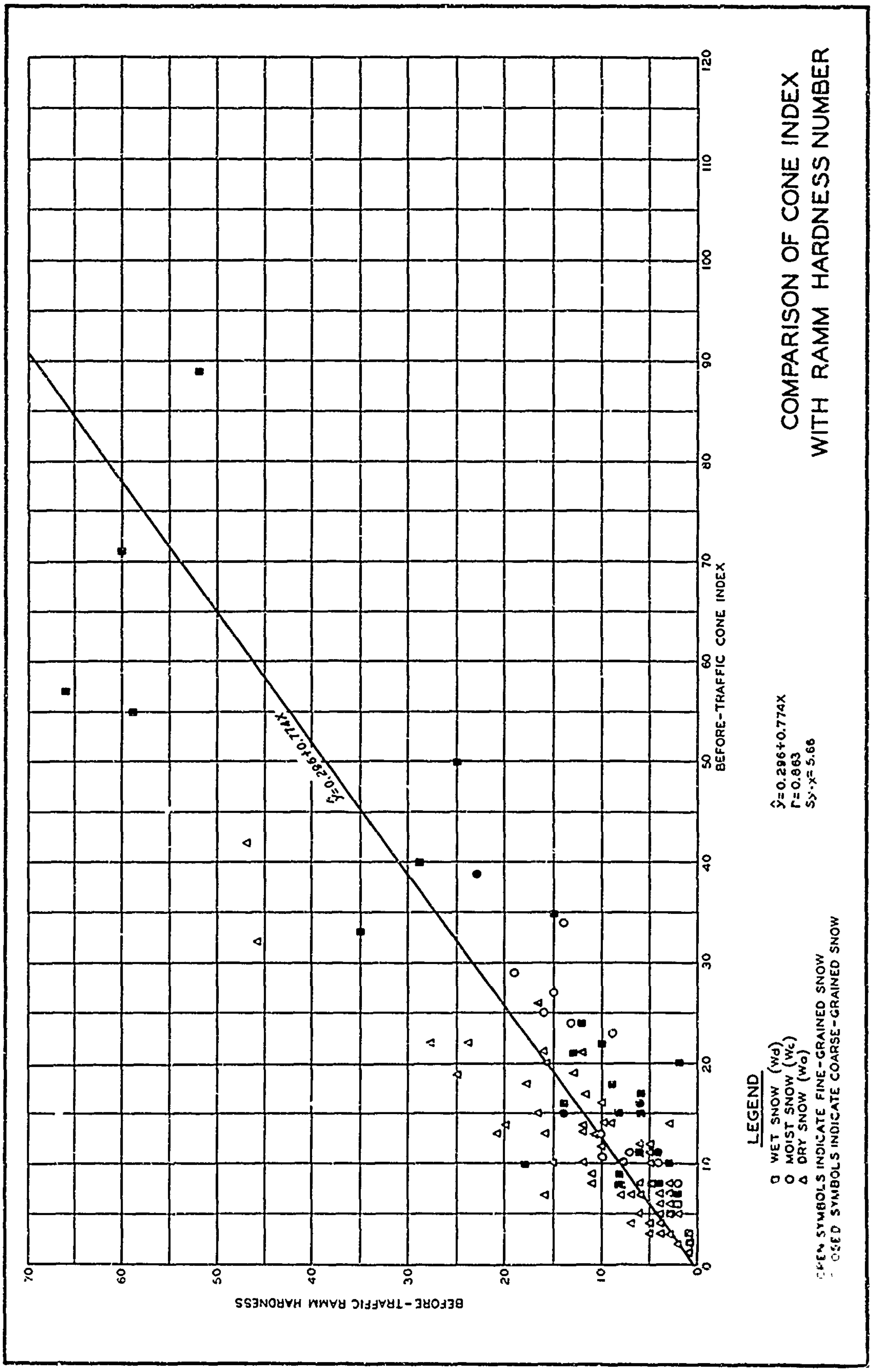
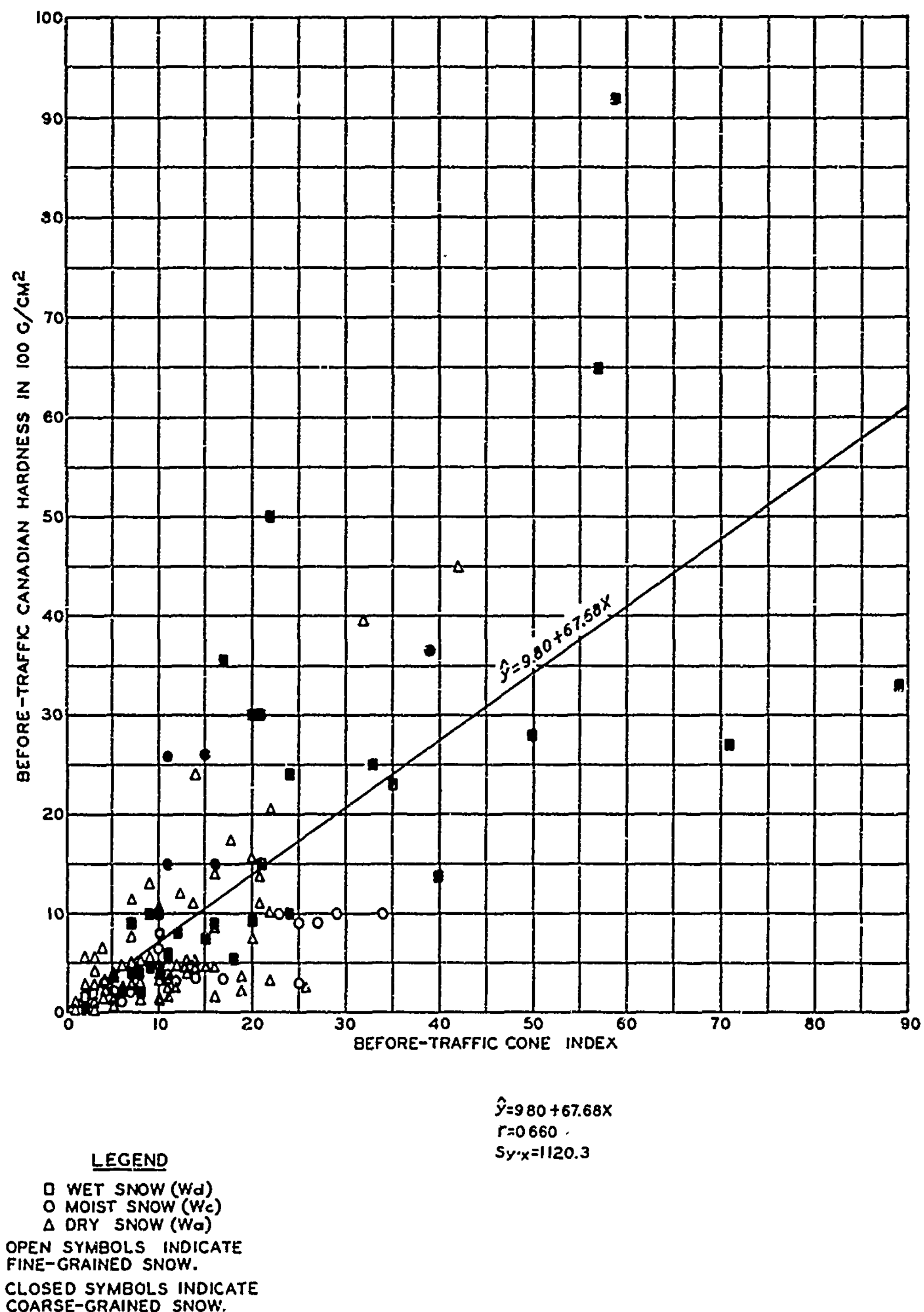
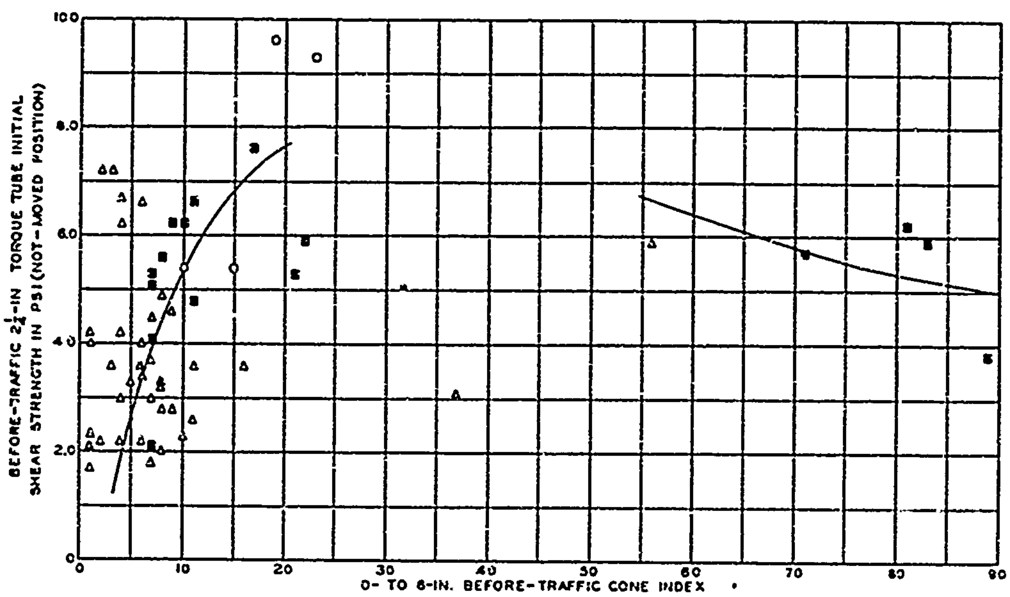

COMPARISON OF CONE INDEX
WITH RAMM HARDNESS NUMBER
BEFORE-TRAFFIC CONE INDEX
BEFORE-TRAFFIC RAMM HARDNESS
$\hat{y}=0.296+0.774X$
$\hat{y}=0.296+0.774X$
r = 0.863
$S_{y \cdot x} = 5.66$
LEGEND
□ WET SNOW (W_d)
○ MOIST SNOW (W_c)
△ DRY SNOW (W_o)
OPEN SYMBOLS INDICATE FINE-GRAINED SNOW
CLOSED SYMBOLS INDICATE COARSE-GRAINED SNOW
0
10
20
30
40
50
60
70
80
90
100
110
120

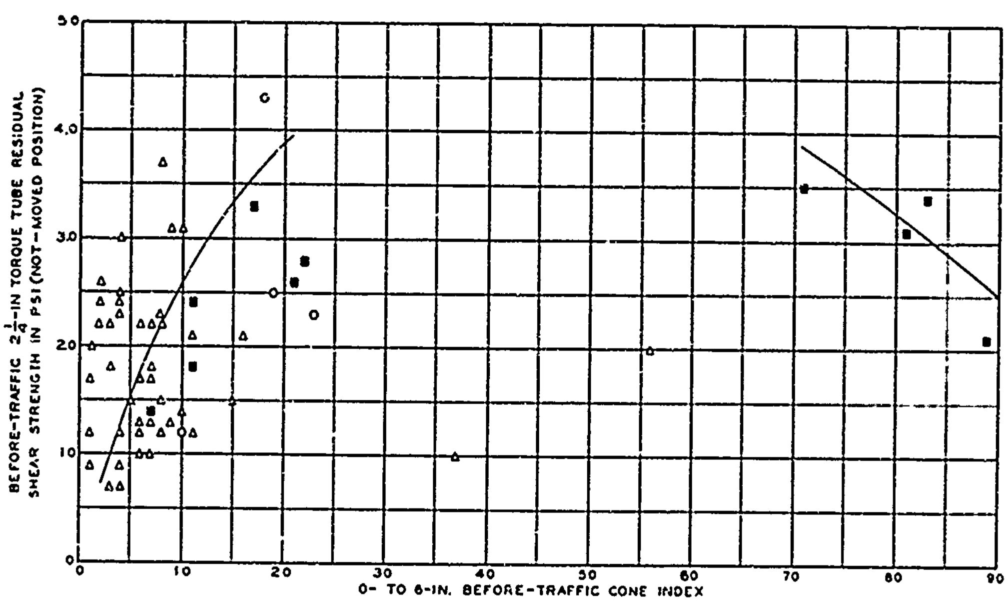
PLATE 68



COMPARISON OF CONE INDEX WITH CANADIAN HARDNESS



INITIAL SHEAR STRENGTH



RESIDUAL SHEAR STRENGTH

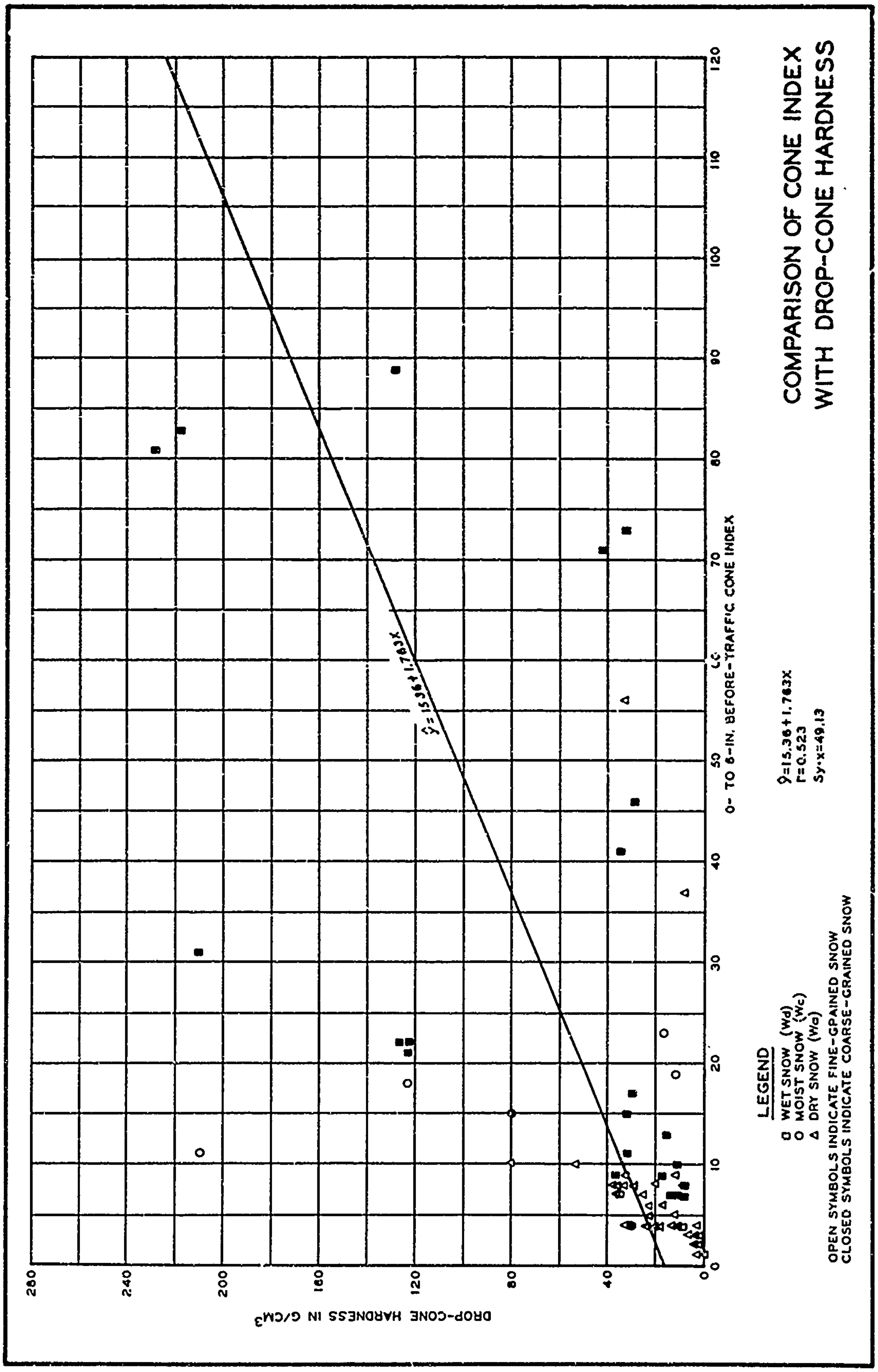
LEGEND

□ WET SNOW (W_d)
○ MOIST SNOW (W_c)
△ DRY SNOW (W_a)

OPEN SYMBOLS INDICATE FINE-GRAINED SNOW
CLOSED SYMBOLS INDICATE COARSE-GRAINED SNOW

COMPARISON OF CONE INDEX WITH $2\frac{1}{4}$-IN. TORQUE TUBE SHEAR STRENGTH (NOT-MOVED POSITION)

PLATE 70


COMPARISON OF CONE INDEX
WITH DROP-CONE HARDNESS
0- TO 6-IN. BEFORE-TRAFFIC CONE INDEX
DROP-CONE HARDNESS IN G/CM3
ŷ = 15.36 + 1.763X
ŷ=15.36+1.763X
r=0.523
Sy·x=49.13
LEGEND
□ WET SNOW (Wd)
○ MOIST SNOW (Wc)
△ DRY SNOW (Wa)
OPEN SYMBOLS INDICATE FINE-GRAINED SNOW
CLOSED SYMBOLS INDICATE COARSE-GRAINED SNOW
0
10
20
30
40
50
60
70
80
90
100
110
120
0
40
80
120
160
200
240
280

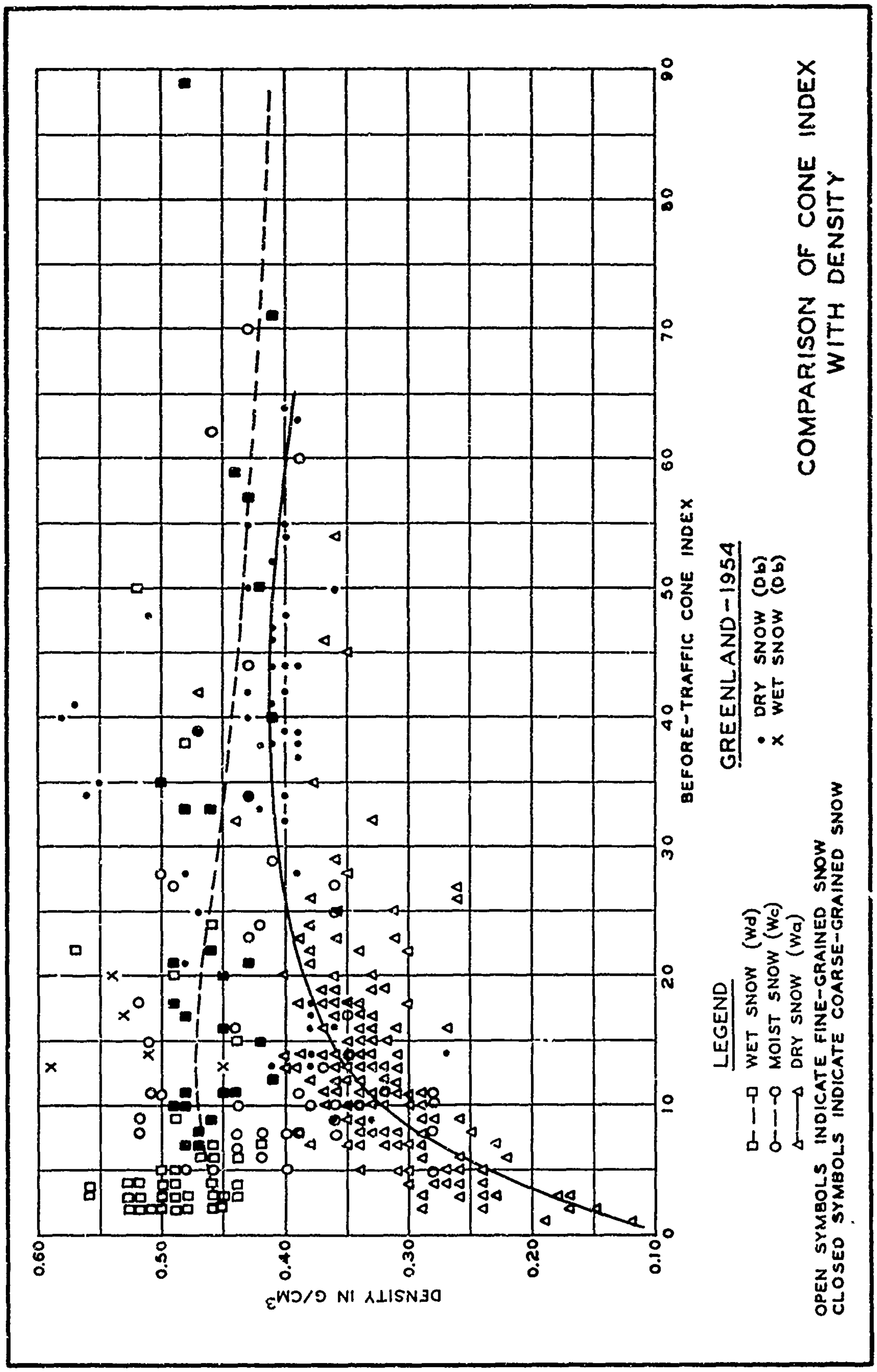

COMPARISON OF CONE INDEX
WITH DENSITY
GREENLAND-1954
• DRY SNOW (Db)
X WET SNOW (Db)
LEGEND
□---□ WET SNOW (Wd)
○---○ MOIST SNOW (Wc)
△---△ DRY SNOW (Wa)
OPEN SYMBOLS INDICATE FINE-GRAINED SNOW
CLOSED SYMBOLS INDICATE COARSE-GRAINED SNOW
BEFORE-TRAFFIC CONE INDEX
DENSITY IN G/CM3
0.10
0.20
0.30
0.40
0.50
0.60
0
10
20
30
40
50
60
70
80
90

PLATE 72

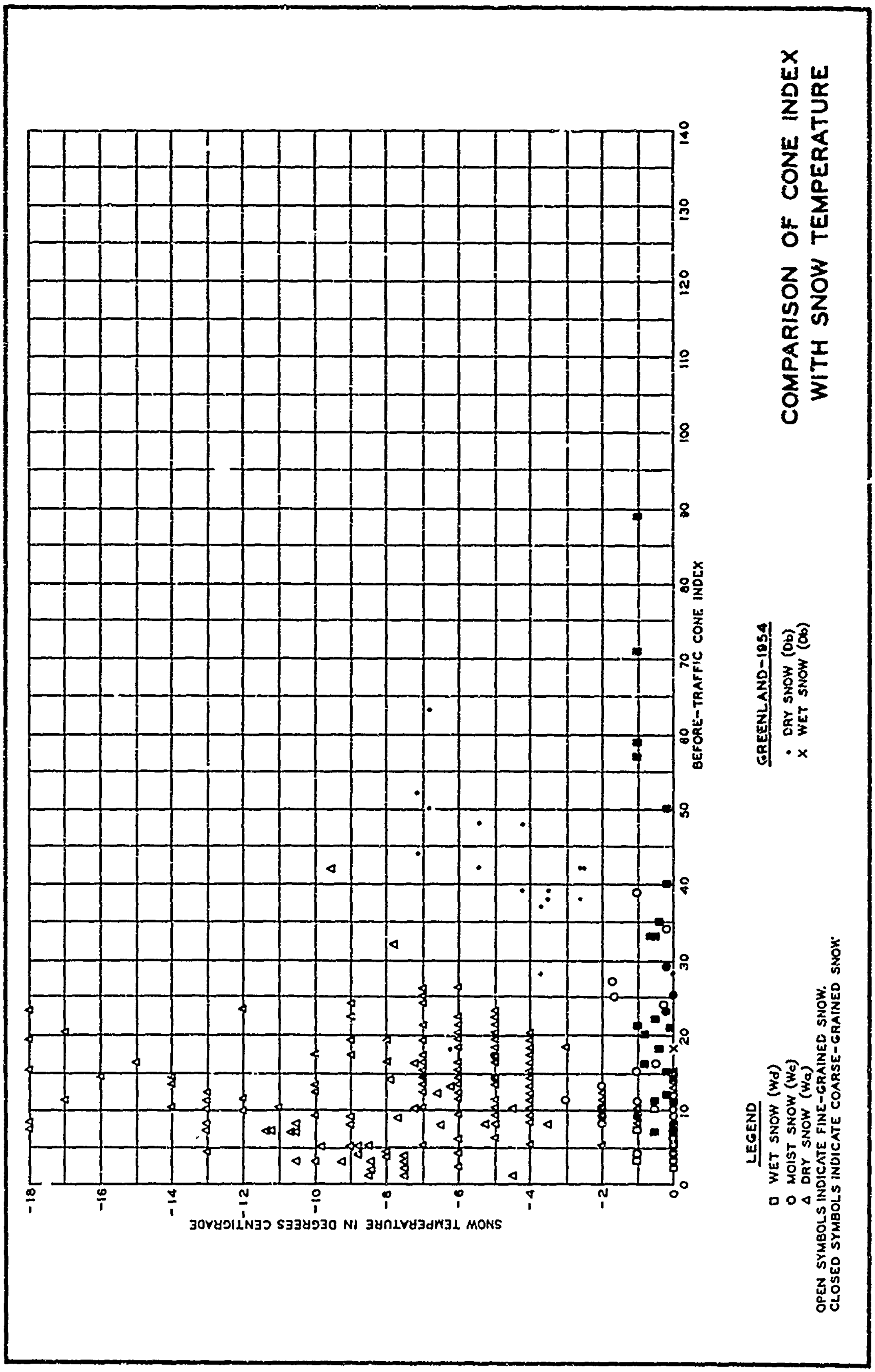

COMPARISON OF CONE INDEX
WITH SNOW TEMPERATURE
SNOW TEMPERATURE IN DEGREES CENTIGRADE
-18 -16 -14 -12 -10 -8 -6 -4 -2 0
BEFORE-TRAFFIC CONE INDEX
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140
LEGEND
□ WET SNOW (Wd)
○ MOIST SNOW (Wc)
△ DRY SNOW (Wa)
OPEN SYMBOLS INDICATE FINE-GRAINED SNOW.
CLOSED SYMBOLS INDICATE COARSE-GRAINED SNOW
GREENLAND-1954
• DRY SNOW (Db)
X WET SNOW (Db)

PLATE 73